AD-A199 715

(1)

ESL-TR-86-13
VOL I OF III

# FIRE PROTECTION SYSTEM FOR HARDENED AIRCRAFT SHELTERS VOL I OF III: DISCUSSION AND APPENDIXES A-C

D.M. ZALLEN, E.T. MOREHOUSE, B.R. DEES,
J.L. WALKER, P. CAMPBELL

NEW MEXICO ENGINEERING RESEARCH INSTITUTE
BOX 25, UNIVERSITY OF NEW MEXICO
ALBUQUERQUE NM 87131

OCTOBER 1987

FINAL REPORT
OCTOBER 1984 - AUGUST 1987



APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

AFESC

AIR FORCE ENGINEERING AND SERVICES CENTER

ENGINEERING & SERVICES LABORATORY
AIR FORCE ENGINEERING & SERVICES CENTER
TYNDALL AIR FORCE BASE, FLORIDA 32403

NOTICE

The following commercial products (requiring Trademark ®) are mentioned in this report. Because of the frequency of usage, the Trademark was not indicated. If it becomes necessary to reproduce any segment of this document containing any of these names, this notice must be included as part of that reproduction.

Bug Wacker
Eveready
Fulton
Glocoil
Grimes
Perco
Plexiglas
Tygon

Mention of the products listed above does not constitute Air Force endorsement or rejection of these products, and use of information contained herein for advertising purposes without obtaining clearance according to existing contractual agreements is prohibited.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

AD-A199 715

| REPORT DOCUMENTATION PAGE | |
|---|---|
| 1a. REPORT SECURITY CLASSIFICATION: Unclassified | 1b. RESTRICTIVE MARKINGS |
| 2a. SECURITY CLASSIFICATION AUTHORITY | 3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release. Distribution unlimited. |
| 2b. DECLASSIFICATION/DOWNGRADING SCHEDULE | |
| 4. PERFORMING ORGANIZATION REPORT NUMBER(S): NMERI WA3-9 (3.06) | 5. MONITORING ORGANIZATION REPORT NUMBER(S): ESL-TR-86-13 (Vol. I of III) |
| 6a. NAME OF PERFORMING ORGANIZATION: New Mexico Engineering Research Institute; 6b. OFFICE SYMBOL (If applicable): NMERI | 7a. NAME OF MONITORING ORGANIZATION: Engineering and Services Laboratory |
| 6c. ADDRESS (City, State and ZIP Code): Box 25, University of New Mexico, Albuquerque, New Mexico 87131 | 7b. ADDRESS (City, State and ZIP Code): Air Force Engineering and Services Center, Tyndall Air Force Base, Florida 32403 |
| 8a. NAME OF FUNDING/SPONSORING ORGANIZATION: HQ AFESC; 8b. OFFICE SYMBOL (If applicable): RDCF | 9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: Contract No. F29601-84-C-0080 |
| 8c. ADDRESS (City, State and ZIP Code): Tyndall AFB FL 32403-6001 | 10. SOURCE OF FUNDING NOS.: PROGRAM ELEMENT NO. 64708F; PROJECT NO. 2673; TASK NO. 0103; WORK UNIT NO. |

11. TITLE (Include Security Classification): FIRE PROTECTION SYSTEM FOR HARDENED AIRCRAFT SHELTERS (CONTINUED)

12. PERSONAL AUTHOR(S): Dennis M. Zallen, Edward T. Morehouse, Billy R. Dees, Joseph L. Walker and Phyllis Campbell

| 13a. TYPE OF REPORT | 13b. TIME COVERED | 14. DATE OF REPORT (Yr., Mo., Day) | 15. PAGE COUNT |
|---|---|---|---|
| Final Report | FROM 10/84 TO 08/87 | October 1987 | 323 |

16. SUPPLEMENTARY NOTATION: This report is divided into three volumes. Volume I contains the discussion and Appendixes A-C; Volume II contains Appendixes D-G; Volume III contains Appendix H.

| 17. COSATI CODES | | |
|---|---|---|
| FIELD | GROUP | SUB. GR. |
| 02 | 06 | |
| 09 | 01 | |

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number): Hardened Aircraft Shelter ~~(HAS)~~, Fire Detection, Halon, Fire Protection System, Fire Suppression, Fire Extinguishing Agents, JP-4 fuel

19. ABSTRACT (Continue on reverse if necessary and identify by block number)


To keep personnel, aircraft, and munitions safe and ready, a fire protection system for hardened aircraft shelters (HAS) is needed. This report describes the effort to design, integrate, and test a fire protection system to combat fires in HAS, aircraft and associated equipment during hot fueling, defueling and other operations in semihardened aircraft shelters.

The smart and fast detection/suppression system used was required to possess the capability to distinguish between normal operations/events, false stimuli and an actual fire. Halon agents were used for partial flooding tests. Agent toxicity and cleanliness were evaluated and considered in the selection of agents and systems.


| 20. DISTRIBUTION/AVAILABILITY OF ABSTRACT | 21. ABSTRACT SECURITY CLASSIFICATION |
|---|---|
| UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS ☐ | Unclassified |

| 22a. NAME OF RESPONSIBLE INDIVIDUAL | 22b. TELEPHONE NUMBER (Include Area Code) | 22c. OFFICE SYMBOL |
|---|---|---|
| Joseph L. Walker | (904) 283-6194 | HQ AFESC/RDCF |

DD FORM 1473, 83 APR EDITION OF 1 JAN 73 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

11. TITLE (CONCLUDED)

Volume I of III: Discussion and Appendixes A-C

18. SUBJECT TERMS (CONCLUDED)

Cont.

Optical Fire detector (OFD)

19. ABSTRACT (CONCLUDED)

This report describes the five-part approach used to develop a fire protection system for HAS:

1. Define the HAS environment,
2. Analyze the HAS environment to determine the most likely fire scenarios,
3. Conduct thorough tests and evaluations of commerically available fire detectors,
4. Design, implement and evaluate HAS fire protection system tests, and
5. From the system analyses and tests, develop a purchase description.

This report consists of three volumes. Volume I contains the body of the report and Appendix A, HAS/FPS Test Plan; Appendix B, HAS/FPS Test Results; and Appendix C, Halon Concentration Data. Volume II contains HAS/FPS test reports and specifications from three companies (Appendixes D, E, and F), and the Optical Fire Detector Description (Appendix G). Volume III consists of the HAS/FPS Purchase Description, Appendix H.

## PREFACE

This final report was prepared by the New Mexico Engineering Research Institute (NMERI), University of New Mexico, Albuquerque, New Mexico, under Contract F29601-84-C-0080 for the Engineering and Services Laboratory, Headquarters Air Force Engineering and Services Center, Tyndall Air Force Base, Florida.

The performance period for this effort was from 1 October 1984 through 30 August 1987. The HQ AFESC/RDCF Project Officer's were Capt Edward T. Morehouse Jr. and Joseph L. Walker.

This report is published in three volumes, of which this is Volume I. Volume I contains a discussion and Appendixes A-C. Volume II contains Appendixes D-G, which include proprietary information. Volume III is comprised of Appendix H.

The authors would like to acknowledge the support and assistance provided by the following individuals: Col Ed Maduli, Mr John Crowell, and SMSgt Keith Moser, of USAFE; Chief John C. Stokes and his personnel from Tyndall Air Force Base Fire Department; and Mr Loran M. Womack and his personnel assigned to the Headquarters Air Force Engineering and Services Support Branch (RDCO).

This report has been reviewed by the Public Affairs (PA) Office and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

Joseph L. Walker
JOSEPH L. WALKER
Chief, Fire Technology Branch

LAWRENCE D. HOKANSON, Col, USAF
Director of Engineering & Services Laboratory

ROBERT R. COSTIGAN, Lt Col, USAF
Chief, Engineering Research Division


(The reverse of this page is blank.)

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONCLUDED)

LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

LIST OF FIGURES (CONTINUED)

LIST OF FIGURES (CONCLUDED)

LIST OF TABLES

LIST OF TABLES (CONTINUED)

LIST OF TABLES (CONTINUED)

LIST OF TABLES (CONTINUED)

LIST OF TABLES (CONTINUED)

LIST OF TABLES (CONCLUDED)





(The reverse of this page is blank.)

# SECTION I
# INTRODUCTION

## A. OBJECTIVE

The objective of this effort was to design, integrate, and test a complete fire protection system capable of rapidly and effectively detecting and extinguishing fires which may occur during peacetime and wartime operations and integrated combat turns in hardened aircraft shelters (HAS), so that personnel, aircraft, and munitions may be kept safe and ready.

## B. BACKGROUND

HAS facilities do not have a fire protection system installed. Current fire protection is provided by a 150-pound Halon 1211 wheeled unit within the shelter and by a standby fire truck in the shelter complex. However, it is recognized (AFISC SON) that adequate fire protection is not afforded personnel, aircraft, and equipment during integrated operations in HAS. The delay encountered from fire ignition to manual dispensing of agent onto the fire is unacceptable for protection of crew members and mission-essential weapon systems during training or wartime operations. In a postattack scenario, the HAS automatic fire protection system would relieve firefighting personnel of the task of protecting the HAS, thereby, allowing them to function in other areas.

## C. SCOPE

The scope of the effort consisted of designing, integrating, and testing a fire protection system to combat fires in HAS, aircraft, and associated equipment during hot fueling/defueling and other operations in hardened aircraft shelters. The detection/suppression system components were required to be state of the art and readily available. The detectors had to be able to distinguish between normal operations/events, false stimuli, and an actual fire. Halon agents were used for preliminary tests. Agent toxicity and cleanliness were evaluated and considered in the selection of agents and systems for protection of personnel, aircraft, and munitions.

D. APPROACH

The approach used to develop a fire protection system for hardened aircraft shelters was divided into five parts:

1. Define the HAS environment,

2. Analyze the HAS environment to determine the most likely fire scenarios,

3. Conduct thorough tests and evaluations of commercially available optical fire detectors,

4. Design, implement, and evaluate HAS fire protection system tests, and

5. Use the system tests to develop a purchase description.

The HAS environment includes all equipment, armament, personnel, configurations, and operations concerning aircraft hot fueling/defueling as well as other HAS operations. This includes environmental conditions, munitions occurences, ignition sources, and time intervals for all operations. The analysis of the HAS environment was used to develop a fire protection system that employs reliable state-of-the-art technology. The solution included consideration of agent type, quantity, toxicity, storage, and distribution; nozzle location, quantity and spray; plumbing; probability of false actuations; total system response; application technique; reliability; and maintenance requirements.

The research of the fire protection system for the HAS led to the complete test and evaluation of commercially available optical fire detectors (OFD). Eleven OFDs were subjected to small-scale tests and German Aircraft Shelter (GAS) tests at Kirtland AFB, New Mexico. The GAS tests included clean and dirty lens tests, false alarm tests, and operational tests.

Testing of the total fire protection system (FPS) was conducted at the full-scale Third-Generation shelter at Tyndall AFB, Florida. Three prototype systems : (1) manifold, (2) semimanifold, and (3) modular, were procured from

different fire equipment manufacturers. The shelter was mocked to represent an actual HAS scenario. JP-4 fuel was spilled on the shelter floor and ignited. A second, smaller fire was preburned within a mock aircraft with a footprint of an F-4, and simultaneously allowed to run vertically downward to meet the running fuel spill on the floor. The test results are discussed in Section VI of this report. From the results of these analyses and tests, a purchase description was developed.

This report consists of three volumes. Volume I contains the body of the report and Appendix A, HAS/FPS Test Plan; Appendix B, HAS/FPS Test Results; and Appendix C, Halon Concentration Data. Volume II contains HAS/FPS test reports and specifications from three companies (Appendixes D, E, and F), and the Optical Fire Detector Description (Appendix G). Volume III consists of the HAS/FPS Purchase Description, Appendix H. In the appendix material originated by organizations other than New Mexico Engineering Research Institute, the original number designations for figures and tables have been retained for reader convenience.

# SECTION II

# FIRE PROTECTION SYSTEM (FPS) CRITERIA AND DESIGN STANDARDS

## A. GENERAL CRITERIA

The work accomplished under this subtask culminated in the HAS FPS Purchase Description contained in Appendix H. The following is a summary of the HAS FPS "system" requirements.

1. The FPS should be provided as an entire system, whereby the system contractor is fully responsible for all hardware, installation, maintenance, and spares over the lifetime of the system.

2. The FPS design should be modular, thereby allowing one-time qualification. Such a design provides capability to add or reduce the number of various components without affecting performance and reliability.

3. A zonal detection and suppression approach should be used to reduce personnel trauma, save cost, reduce downtime, and increase reliability of the overall system.

4. The FPS detectors should have a reliability of 0.99 not to signal fire due to any HAS false fire stimuli.

5. The suppression system should be comprised of individual halon bottles either suspended from the ceiling or externally located in a separate hardened structure. Each suppressor should utilize a proven military specification/standard valve.

6. The FPS should be capable of performing in winds of up to 20 mi/h through the open doors of a HAS.

7. The FPS should consider possible false alarm stimuli from engine reheat, wet starts, black powder start backfires, wet APU starts, and other sources.

8. The FPS should be designed according to Military Standards and should function at high reliability in EMI environments and all environments specified in MIL-STD-810.

9. The FPS should be designed to provide 132,000 hours (15 years) mean time between failures (MTBF) for all fire scenarios and over 100,000 years mean time to false dump due to internal electrical component failures. The system must be configured, based upon reliability models according to MIL-HDBK 217D and MIL-STD-756B.

10. Executive action (dumps) should be measured for a fire threshold of $\geq$ 16 $ft^2$ pan size. The FPS should see and extinguish any $\geq$ 16 $ft^2$ fire within 15 seconds, but not respond to small (1 $ft^2$ or less) fires.

11. The FPS should alarm inside a HAS and notify the fire station upon detecting a fire of $\geq$ 16 $ft^2$.

12. The FPS should check itself to determine its own "health." If any part of the FPS does not function according to operational requirements, a fault alarm should be initiated, providing remote status to the base fire station. The base Civil Engineer and the local contractor's office should then be contacted by telephone and the FPS brought back to full certified operation through service. Under no condition should any HAS FPS be down or off-line for more than 12 consecutive hours.

13. The system contractor should provide all hardware, install all FPSs, provide all maintenance, provide all spare parts, maintain the FPS's MTBF at a high level--"a system contractor approach."

14. The system design should include protection against Electromagnetic Interference (EMI).

15. Nuclear hardening precaution should be provided as an option.

16. The FPS should be designed to provide for safe egress of personnel.

17. A suppressor should be provided to extinguish aircraft nacelle fires.

18. Periodic service should be conducted to clean detector windows and keep the FPS reliability at a high level.

19. The contractor must ensure the availability of necessary resources, capital, and continued service, and continued availability of spare parts that are necessary to implement the entire program successfully.

20. The contractor should be required to develop, certify, deliver, install, and maintain the complete FPS. All components and subsystems of the FPS, along with other functional and hardware interfaces in a HAS and on the airbases, must be designed and qualified from a systems approach to reliability and performance.

## B. GENERAL DESIGN GOAL

The overall general design goal incorporates:

- Maximum reliability.
- Minimum maintenance.
- Simplicity in servicing.
- Ease of installation without impeding HAS operations.
- Ability to refurbish rapidly after an activation or fault.
- Adherence to the full military standards specified.
- Protection against false dumps from specified external stimuli.
- Protection against false dumps from internal stimuli.
- Maximum effective inertion.
- Cost effectiveness.
- Flexibility with no overall design changes for all HAS sizes and configurations.

- Minimization of trauma to personnel.
- Ability to function as a system.
- Continuity of system management and spare parts.
- Maximum safety for all personnel and internal equipment.

1. FPS Design Standards

The full system shall be designed to meet the following standards.

MIL-STD-810C
MIL-STD-202H
MIL-STD-461E
MIL-STD-462H
MIL-STD-454H
MIL-STD-199
MIL-STD-198
MIL-STD-833
MIL-STD-217D
MIL-STD-756B
MIL-STD-108E
DOT-STD-1986
BS 5501 (detector only): Part 1:1977.
BS 5501 (all components): Part 5, flameproof enclosure
BS 2011 Part I (environmental section)
BS 800 (1977) radio interference
BS 5420 IP 67
BS 5045
BS 6436
BS 5445
EN 50014
EN 50018

Other codes associated with specific countries where HASs are located, if applicable.

2. HAS FPS Configuration: Modular and Zonal

The HAS FPS should be directly adaptable to all HAS types and sizes without any change in overall design. The system configuration should be modular and zonal and consist of the following major subsystems: (1) fire detectors, (2) extinguishers, (3) control electronics, (4) back-up power, and (5) various alarms, safety devices, and sensors. The overall system should only vary between different HAS types and sizes in the number of subsystem components.

3. Fire Detection Geometry

The fire detection subsystem should consist of sensors, divided into zones of multiple sensors each.

The FPS should not "dump" the suppressant in any zone unless the operational mode minimum fire size condition is "seen" by detectors voting in that zone, but under no condition should the FPS dump any halon in response to small fires of approximately 1 $ft^2$ area at any floor location in the HAS.

4. Fire Suppression Geometry

The fire suppression subsystem should be divided into zones. The number of suppressors should be selected such that a nominal halon suppressant concentration of greater than 4.7 percent by volume throughout the hazardous area of HAS is attained within 10 seconds of discharge to suppress all fires within 15 seconds of detection without possibility of reignition. This concentration must be sustained against any prevailing turbulences and/or wind conditions of up to 25 mi/h. The halon suppressors may be suspended from the walls along both sides of the HAS at a height of no less than 10 feet. The suppressant containers may be located outside the shelter if the NATO criteria for semihardened facilities are met.

5. Fault Self-Test

The FPS should be designed to provide self-check of all major components to determine the operational status at each FPS. In addition, the FPS should have the capability of real-time monitoring of some major system

parameters. The contractor should demonstrate via system analysis which functions should be monitored and checked.

6. Full System Test

The FPS should be reviewed periodically to maintain a long period of MTBF. The contractor should demonstrate via analysis and reliability modeling why the proposed time interval was selected.

7. Maintenance/Service

The contractor should maintain facilities close enough to any airbase to allow a 12-hour turnaround time. These facilities should also provide adequate storage of FPS spare components that may be required as replacements. This requirement holds for all base locations except those in Turkey, where the contractor's maintenance personnel, equipment, and spare parts will be located on base.

The contractor should demonstrate via tradeoff studies and reliability analysis why the proposed time to repair/service was selected.

A data log should be kept for each HAS FPS, which contains component renewal schedules, detailed records of tests, replacements, and status.

## SECTION III

## HARDENED AIRCRAFT SHELTER (HAS) ENVIRONMENT

### A. GENERAL DESCRIPTION

A HAS in U.S. Air Force-Europe (USAFE) or Pacific Air Forces (PACAF) is an aboveground storage shelter for protecting aircraft, support equipment, and operations personnel from conventional attack. These are of four types because progressive generations of HASs were developed as the need to house larger, more sophisticated aircraft and the corresponding support equipment arose. The HAS design is approximately that of a semicylinder with double-layer, steel-reinforced concrete walls. A HAS has a large, steel-reinforced concrete door, closed by a motor in 1 minute, 40 seconds. The motor now in use is being replaced by an updated explosion-proof model. A small personnel door is located in the front door on the side, and steel doors at the rear are opened during jet engine operation to let the aircraft engine exhaust exit through the rear exhaust port. HASs are generally located in clusters or rows.

The basic function of the HAS is to protect the personnel, aircraft, and necessary support equipment. F-4, F-5, F-15, F-16, A-7, A-10, A-037, F-106, F-111, and various types of NATO aircraft may be stored in a HAS. The aircraft may be pulled into the HAS by a winching mechanism located at the rear of the HAS or taxied into place by push/tow trucks. The jet engines on aircraft may be running, started, or stopped while in the HAS. Generally, only one aircraft is placed in the shelter, although some HAS facilities have room for three. Mobile fuel trucks (R-5 and R-9 types with 5000 gallons of jet fuel) may be stored in a HAS, but this method of fueling is being replaced by a pantograph with underground fuel tanks. (A pantograph is an articulating pipe assembly from the wall/floor fuel valve that rolls along the floor to the airplane to dispense fuel.) Breathing air is drawn from ducts at the top of the HAS, exits through ports in rectangular ducts running along the floor at the sides, and is blown by squirrel-cage fans out the rear of the shelter. This type of ventilation system is now being updated. Munitions racks are arranged from the front to the rear of the shelter next to the air ducts. Other support equipment inside the shelter may consist of start-carts, generators, welders, and munitions-loading equipment. Each HAS contains a

150-180-pound halon-wheeled unit for extinguishing small fires. Personnel in the HAS (including aircraft crews) may or may not be wearing clothing necessary under chemical warfare conditions.

## B. FIRE SCENARIO

In a fire situation, the HAS may be considered to be an open system because of

1. The long closing time of the front door,

2. Airflow resulting from use of the breathing-air exhaust fans, and

3. Airflow caused by an operating jet engine and exhausting through the open exhaust port at the rear of the HAS.

Therefore, the use of gaseous firefighting agents would require detailed knowledge of the air patterns inside the HAS to maintain desired concentrations of the agent. A clean liquid agent would be desirable for storage and throw and would help to cool munitions. Water is not available at the HAS. Ambient weather conditions may promote condensation on the walls and floor of the shelter.

Numerous fire scenarios may develop inside the shelter. The most likely case is a fuel spill caused by damaged fuel hoses, improper filler connections, damaged aircraft, or malfunctioning support equipment. A fuel spill is potentially the most dangerous situation because of the likelihood of its spreading under fuel tanks and munitions. Potential ignition hazards exist from non-explosion-proof motors used to close the front doors, high-voltage generators and start-carts, hydraulic carts, cartridge starts using slow-burning black powders, running jet engines, static electricity, and human error. Electrical fire hazards are present with the high-voltage generators and start-carts.

At least three fire or potential fire incidents have occurred in HASs. One incident involved the transfer of jet fuel from a 5000-gallon truck to an aircraft. A hose broke during the refueling operation, resulting in a spill of over 100 gallons. Fortunately the fuel did not ignite. The second incident involved the internal ignition of a hydraulic cart within a shelter next

to an aircraft. A few thousand gallons of Aqueous Film-Forming Foam (AFFF) ensured extinguishment of the cart without incident to the aircraft. Another incident involved the rupture of a fuel transfer segment within the aircraft pylon during fuel transfer from a 5000-gallon truck to the single-point refueling connection. Fuel sprayed in the air on the wall and onto the floor. The closed door could not be winched open because the motor was not explosion-proof. After personnel sprayed AFFF with a handline and disconnected the drive gear pin, the door was pulled open. Application of AFFF onto the fuel and washdown continued without a fire incident.

## C. AUTOMATIC FIRE PROTECTION SYSTEM (AFPS)

The function of the automatic fire protection system (AFPS) is to keep personnel safe, and aircraft and support equipment operational. This implies the following requirements:

1. Detection and suppression of large fires within 30 seconds,
2. Clean extinguishing agents,
3. Highest reliability and unattended operation of the AFPS, and
4. Prevention of munitions heating for more than 30 seconds; cooling during and after fire suppression is desirable.

The fire detectors used must be able to detect a fire and dump extinguishing agent within 10 seconds, but must not be susceptible to any false stimuli. Possible false detection sources are lightning, welding sparks, aircraft engine exhausts/afterburners, aircraft engine starts/stops/misfires, radar, communications, lights, sunlight, heaters, clothing, cigars, cigarettes, matches, cigarette lighters, and electronic warfare equipment. The large numbers of insects present during some seasons may block the optical signal necessary for detection or cause false alarms. This has been noted for some detectors located in warehouses in rural farming areas. Water present on the floor of the shelter from condensation or rain may influence certain types of detectors. Dust on the surface of the optical windows may reduce the sensitivity of some detectors. Thus, a discriminating and reliable detection system is necessary to prevent false dumps.

## D. SUBSTRATE TESTING

Testing was conducted on substrates used in optical fire detectors involved in the HAS effort. The purpose of this task was to determine the nature of foreign material that may deposit on the substrate during normal HAS operations over a period of time, and which ultimately lowers the ability of the detector to observe a fire situation. The detectors operate at particular wavelength bands in the infrared (IR) and/or ultraviolet (UV) region of the optical spectrum; therefore, it was important to determine the influence of dirt deposits on the efficiency of the detector. In addition, qualitative information was needed to determine the detection loss that occurs when the substrate becomes dirty.

Three substrate materials were involved in the testing program: calcium fluoride, quartz, and sapphire. The calcium fluoride material was initially used to establish baseline data regarding the soot deposits and the reduced visibility. This material is not a detector substrate, but is inexpensive and has negligible absorption in the UV and IR regions of the spectrum; therefore, it served as an excellent material for the preliminary testing. The calcium fluoride substrate was 5 inches in diameter and less than 1/8 inch thick. The quartz and sapphire materials were actual substrates used in the detectors. Each quartz substrate was 1 1/2 inches in diameter and less than 1/8 inch thick. The sapphire substrates were 1 1/4 inches in diameter and of the same thickness as the others.

The quartz window is only used for the UV detectors. Quartz substrate is opaque to radiation with a wavelength shorter than 185 nm. The quartz provides the lower limit for the Geiger-Muller detector, which operates between 185-245 nm. Quartz is not used for IR detectors because of its high absorbance in the 4.0-4.6 μ range.

Sapphire is a superior window material for the IR detectors. Sapphire has an 87 percent transmittance from 0.3 μ (300 nm) to 4.6 μ. The 50 percent transmittance points for sapphire are 0.150 μ and 5.5 μ.

The spectroscopic techniques used for analyses of the materials included IR, UV, and visible spectroscopy for the substrates, and gas chromatography/mass spectrometry for the particulate matter obtained from the substrates.

Each of the clean substrates was analyzed separately by IR and ultraviolet-visible (UV-vis) spectroscopy to obtain baseline data on absorbances that might be inherent in the substrate materials. The calcium fluoride substrate was then placed in a burning JP-4 environment so that soot was deposited on the substrate. The dirty substrate was analyzed again, using IR and UV-VIS spectroscopy to detect additional absorption bands from the soot material. In addition, the soot was removed and analyzed by gas chromatography/mass spectrometry to determine the compounds that had been deposited during the JP-4 burning operation. The quartz and sapphire substrates were mounted in holders and placed in actual HAS environments located in Germany and England for periods of approximately 120 days. Multiple samples of each substrate material were mounted in each shelter. After removal from the shelters, these dirty substrates were analyzed by IR and UV-vis spectroscopy to determine the additional absorbances from the contaminants. The results from these tests and their impact on the ability of the detector to detect a fire are discussed in the following paragraphs.

The detectors involved in this study all operate in the 1.2-4.6 μ IR range and/or the 185-280 nm UV range. As described in Section V, the 4.0-4.6 μ IR range is predominantly used because that is the wavelength band of $CO_2$ emissions. For dual IR detectors the 3.4-4.0 μ band is also used. The 185-245 nm range is the major range of interest for the UV Geiger-Muller detectors. One detector using different technology operated in the 1.2-2.9 μ mid-IR band and the 245-280 nm mid-UV band. This detector also detects radiation in the visible range of 500-650 nm.

## E. RESULTS OF ANALYSIS OF CALCIUM FLUORIDE SUBSTRATES

A baseline was run on the test instrument with no sample from 200-12000 nm. The clean calcium fluoride substrate was tested and the results are shown in Figure 1. The clean substrate had 94 percent transmittance from 200-6000 nm except for a slight roll-off at 200 nm. Above 6000 nm (6 μ) the transmittance degraded down to 0 percent at approximately 11 μ.

Figure 1 also shows the transmittance of the two tests of the dirty substrate. The figure shows that in the UV-vis region the transmittance is reduced by 20-30 percent, with the second test measuring a dirtier portion of the substrate.

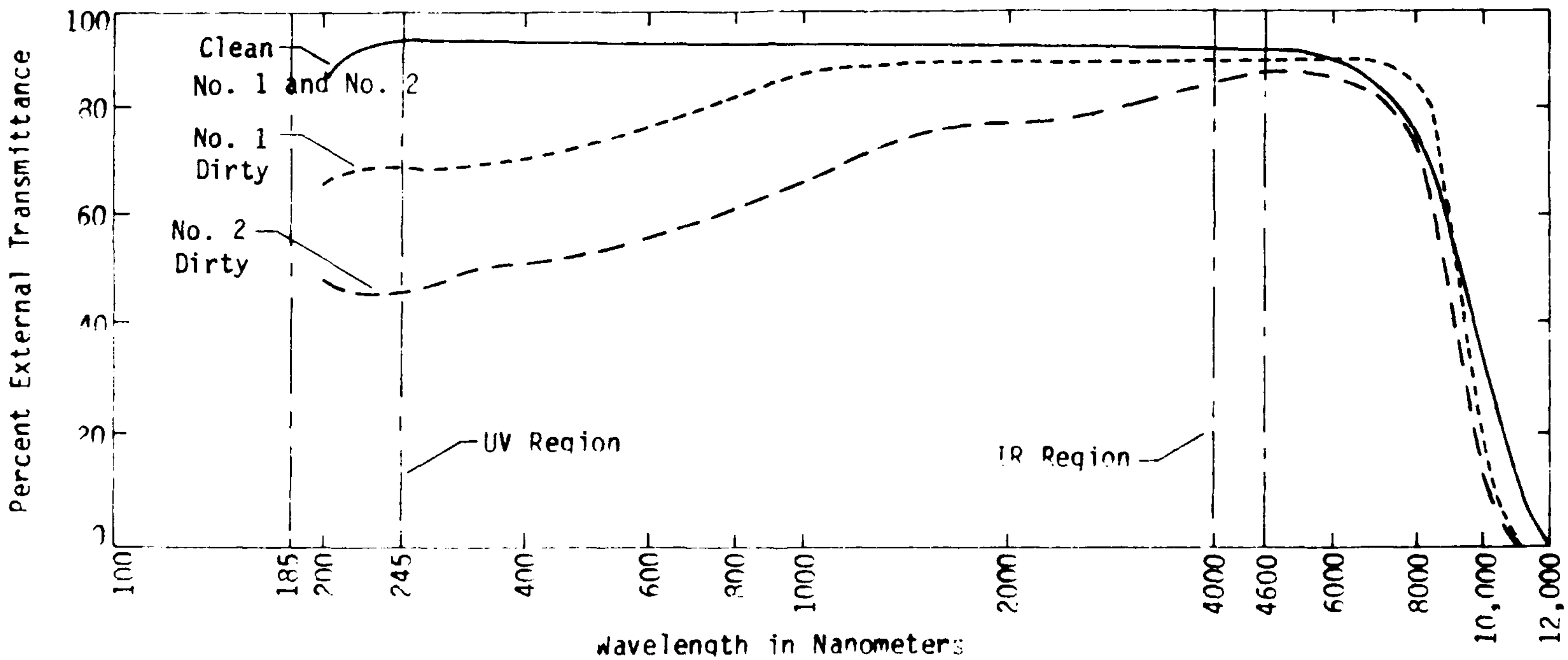



Figure 1. Calcium Fluoride Substrate Absorption Spectra.

## F. RESULTS OF ANALYSIS OF QUARTZ SUBSTRATES

Figure 2 shows the transmittance of the clean and dirty quartz substrates. The dirty substrates were placed in HASs in Germany and England, one in front and one in the rear of the shelter, at each location. The transmittances of the dirty substrates were 5-10 percent less than that of the clean, except in the UV range, where the transmittance was reduced by 20-40 percent.

## G. RESULTS OF ANALYSIS OF SAPPHIRE SUBSTRATES

Two sapphire substrates were placed in the HAS located in England and another two in Germany. The two in Germany are still in the shelters at this time, so only the England substrates were analyzed. Sapphire has a large absorbance in the UV range, as demonstrated by the clean substrate in Figure 3. However, the dirty substrate increased that absorbance by as much as 20 percent.

When comparing each dirty substrate with its corresponding clean substrate, there were either no differences or very small ones between the two in the IR region. In the UV-vis spectra obtained, there were very significant differences between the clean and dirty. In all three materials the dirty substrates showed a large decrease in the transmittance (between 20-40 percent) in the region of about 200-250 nm. This seems to be the most sensitive area, where the foreign material deposited on the substrates may interfere with the ability of the detector to detect the fire. The fact that the degradation of all three substrates was essentially the same indicated that the laboratory tests on the calcium fluoride material were adequate indicators of the amount of material that might be deposited on the substrate over a period of 120 days.

Soot deposited on the substrates, either under laboratory conditions or in the actual shelters, was removed and analyzed using mass spectroscopy. In the laboratory testing, the burned JP-4 soot was deposited on a piece of Plexiglas, then scraped off for analysis. The quartz and sapphire substrates were placed in the HAS sites in Germany and England. The material found on the Plexiglas was of much higher molecular weight than that found in the

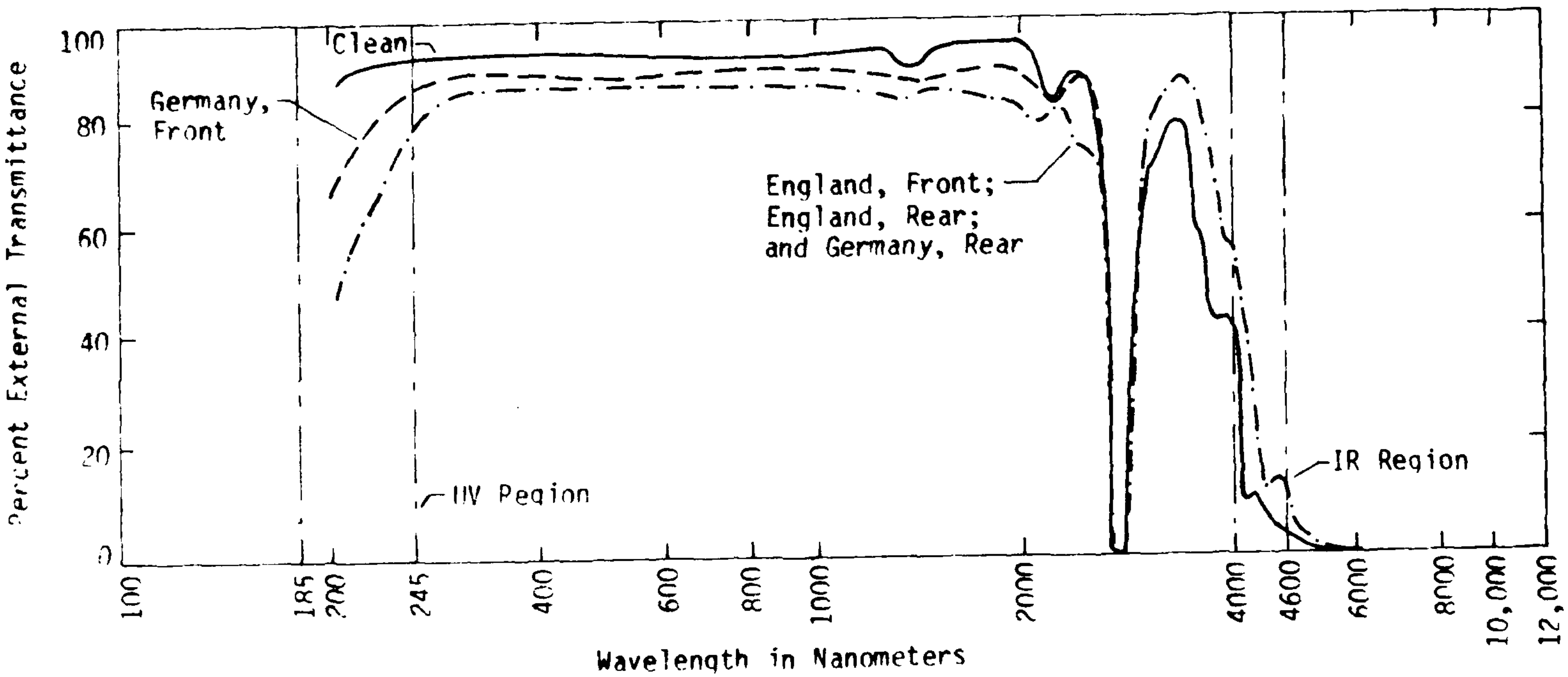



Figure 2. Quartz Substrate Absorption Spectra.

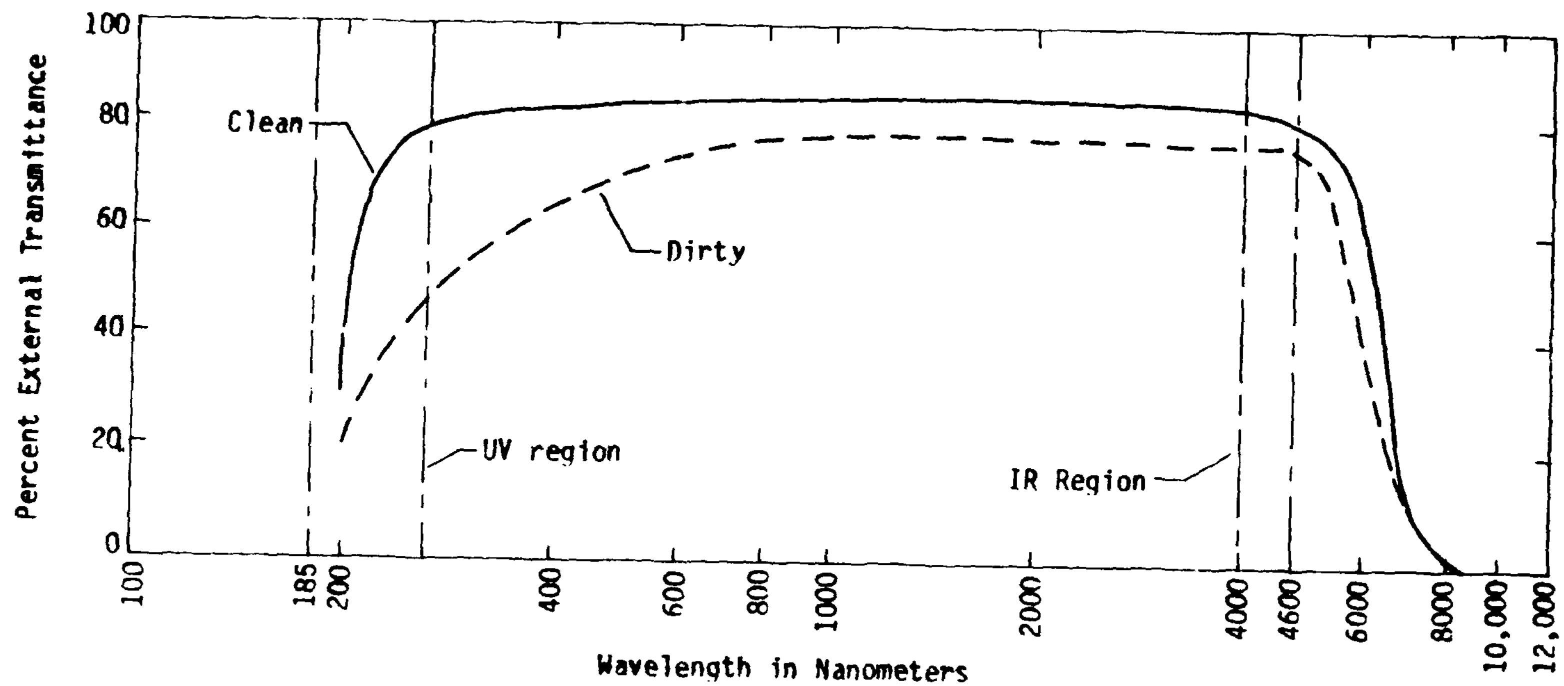



Figure 3. Sapphire Substrate Absorption Spectra.

actual environments. However, in the lower molecular weight area, the material was essentially the same. Since the soot is a mixture of many different molecules, it is difficult to identify the actual species present, but some general classes of compounds can be identified. The mass spectra of all the substrate soot materials indicated that saturated hydrocarbons and aromatics were present. This was shown by the appearance of peaks at 43, 57, and 71 atomic mass units for the saturated alkanes, and at 77 atomic mass units for the aromatics. In the case of the materials from the actual shelters, there was also evidence of sulfur material. This was not observed in the Plexiglas substrate.

In summary, the reduction of percent transmittance for the substrate that was dirtied in the laboratory was not too dissimilar to that found for substrates hung in the shelters for 120 days. The reductions also occurred in the same regions of the spectrum. The soot found on all three substrates was analyzed by mass spectrometry and was essentially the same, with the exception of higher molecular weight material found on the calcium fluoride. However, these latter peaks were much lower in intensity and, therefore, did not contribute very much to the total.

## SECTION IV
## SOLUTION INVESTIGATION

In the HAS environment, the combustible material presenting the greatest danger is JP-4. Large spills of this material can ignite with an almost explosive nature. Consequently, the rapid detection and suppression of fire in a HAS is essential.

A variety of sensors on the market are used to detect fire or the byproducts of fire. These sensors range from highly sophisticated optical detectors to simple fusible links which melt at a specific temperature. To best select a detection system for the HAS, an extensive survey was conducted to understand the limitations and sensitivity and the operating, maintenance and installation requirements associated with each type of system. A brief summary of the available detection systems follows.

### A. SMOKE DETECTORS

#### 1. Photoelectric and Ionization Detectors

There are two basic types of smoke detectors available: the photoelectric detector and the ionization detector.

The photoelectric detector works on the principle that smoke will tend to attenuate a light source. One type of photoelectric detector is composed of a chamber into which smoke is allowed to enter, but into which light from the environment is restricted from entering. The intensity of a light source located within the smoke chamber is continuously monitored. When the light intensity is degraded as a result of obscuration by smoke, an alarm is triggered.

Another type of photoelectric detector works on a similar principle of having a light source located in a smoke chamber from which outside light is restricted. A photocell is located within the smoke chamber; however, it is mounted in such a way that, in the normal operating mode, it does not see the light source. When smoke enters the chamber, light is scattered by the smoke particles and picked up by the photocell, which triggers an alarm.

The ionization detector operates on a different principle from that of the photoelectric detector. Ionization detectors generally have two chambers, one of which smoke is allowed to enter, and the other of which is maintained smoke-free for use as a standard. A radioactive material such as Americium-241, which ionizes the air inside the chambers, is located within the chamber. As a result, a slight current flows between the two electrodes located within each of the chambers. When smoke enters the chamber open to the environment, the smoke absorbs some of the alpha particles being emitted by the radioactive source and decreases the current passing between the two electrodes. The difference in the current levels of each chamber is sensed and an alarm is triggered.

Smoke detectors have received a great deal of praise for their application in residential settings. Many lives have been saved and property damage avoided because of these devices. However, smoke detectors do not have an advantageous application in the HAS environment for several reasons. First, the false alarm rate from a smoke detector system is expected to be quite high. The HAS environment has diesel trucks and generators as well as aircraft operating within; these are noted for alarming smoke detectors. Second, the HAS environment is dirty. Dust and exhaust residue accumulate throughout. This accumulation of various residues would either desensitize a smoke detection system, or create a condition in which the detector would continuously alarm, depending on the type of detector used. Periodic replacement of the photoelectric ionization detectors would be necessary because they are not manufactured in a way that allows them to be serviced. Finally, the response time of the smoke detectors would be too slow for sole application in HAS.

2. Beam Detectors

A third type of smoke detector, which is newer and much more expensive per unit, is the beam detector. It consists of two separate units, a transmitter and a receiver, separated by as much as 100 feet. The transmitter emits a modulated infrared beam which is monitored by the receiver. Under normal (no-smoke) conditions, the receiver senses the beam at a specific signal level. When smoke passes through the beam, the infrared light is

attenuated. If the received signal falls below a specific level, the receiver actuates an alarm condition. Long-term changes to the received signal caused by environmental variations are offset by the compensation circuit of the receiver. If the limit of the compensation circuit is reached, or a housing cover is removed, the detector will signal a trouble condition.

Maintenance required by the beam detectors in a HAS environment, although simple, must take place frequently. Maintenance crews would be required to wipe off the face of the detectors with a moist cloth. It is uncertain if this should be done once a day or once a month. More experience with the beam detector system will be necessary before a maintenance schedule can be recommended; however, this system was not designed to be used in an environment as harsh as that in a HAS.

The beam detector is not thought to be a realistic method of detection for the HAS system for several reasons. First, before the detector can respond to a fire, smoke must make its way into the path of the detector beam and attenuate the signal sufficiently for a specific period of time. For the system to be made relatively free from false alarms, it would have to be desensitized to the point where exorbitant time delays would be experienced by the suppression system. This time delay would not be acceptable. Second, it is not possible to program the detection system to discriminate between the smoke resulting from a welder or diesel engine and smoke resulting from a fire. This capability to discriminate is a necessity. Finally, if the shelter doors are open and a breeze is blowing through the shelter, the smoke from a fire may not even reach the detection system until the fire is out of control.

5. RATE-OF-RISE DETECTORS

At least two types of thermal detectors are used to monitor the rate at which the ambient temperature changes. The first of these detectors consists of an air chamber, a flexible metal diaphragm, and a calibrated vent. Normal day-to-day temperature fluctuations are automatically compensated for by the [illegible] action of the vent. When a fire occurs, the temperature rises quickly and the air in the chamber expands faster than it can be vented; thereby, pressure which pushes against the diaphragm and closes an electrical

contact is created. The rate of rise is generally designed to operate when the temperature rise is 15 °F/min. However, a faster rise will cause faster response. As the temperature decreases, the diaphragm self-restores and opens the electrical contacts.

The second type of rate-of-rise detector takes advantage of the rate at which heat can be conducted from one material into another. In this detector, a highly conductive sleeve encompasses two expansion struts. As the ambient temperature changes, heat is conducted from the sleeve into the expansion struts. The sleeve is mechanically connected to the expansion struts in such a way that if the sleeve expands at a rate significantly higher than that at which the expansion struts expand, the struts are pulled close together and two silver contacts are joined. Under normal operating conditions, heat is conducted from the sleeve into the joining expansion struts, and the assemblies expand together. A thermostat which signals an alarm at a present temperature regardless of the rate of temperature increase is usually also embodied in these detectors.

Again, these devices do not have a primary application in the HAS. The temperature fluctuations witnin the HAS are very great because of the startup procedures of aircraft and the normal operations that take place within the shelter, and these variations would result in numerous false alarms. Also, the rate-of-rise detector response time is too slow for the HAS application.

C. HEAT-SENSITIVE WIRE

Another device used for detecting fires is heat-sensitive wire. The detector probe is constructed of two wires individually encased in a heat-sensitive material. The encased actuators are twisted together to impose a spring pressure between them, then spirally wrapped with a protective tape and finished with an outer covering to suit the environment of use. At installation a device is connected to one end of the actuators so that, when a power source is added, a small monitoring current passes continuously through the detector. At the critical or operating temperature, the heat-sensitive material yields to the pressure on it, permitting the actuators to move into contact with each other.

A similar alarm device featuring a semiconductor material and a stainless steel capillary tube has been used where mechanical stability is more important. The capillary tube contains a coaxial center conductor separated from the tube wall by a temperature-sensitive glass semiconductor material. Under normal conditions, a small current flows in the circuit between the stainless steel capillary tube and the center conductor. As the temperature rises, the resistance of the semiconductor separating the two decreases, allowing more current flow and thus initiating an alarm. This device is sometimes referred to as thermistor wire.

Heat-sensitive wire and thermistor wire are not feasible in the HAS because of the temperatures reached during the normal operation of the shelter, and the inability of the detector to respond to small fires which can escalate. Heat-sensitive wire works best when it is close to the source of the heat. This would not be possible in a HAS because of the constraints imposed by operations in the structure. Additionally, if heat-sensitive wire were located close to the areas where a fire might be expected, it would be subject to potential physical damage. This would result in a false dump of the suppression system.

## D. OPTICAL DETECTORS

Fire produces radiation in a multitude of wavelengths ranging from the UV to the far IR. Optical detectors generally consider a small band of radiation and look for characteristics indicative of fire within these bands. However, fire is not the only source of radiation within the HAS. When an aircraft is pulled into the HAS its engines may be running, its brakes are hot, and diesel equipment is operating near the aircraft. These all cause emissions of IR radiation. The sun is also a very rich source of both UV and IR radiation.

Numerous filtering techniques have been developed to eliminate optical false alarm sources. Multiple bands of radiation and signal microprocessing are often considered to further reduce the chances of false alarms. Self-checks are typically built into optical detectors to insure the proper operation of the sensor and the associated electrical hardware, thereby, providing a very reliable method of detecting the presence of fires.

Of the methods currently available to detect fire, optical detectors offer the most reliable method of identifying a fire in the HAS, in addition to being least susceptible to false alarms. False-alarm immunity is good because of multiple wavelengths, correlations (auto-, cross-, and ratio), and timing (fire flickers and gate delays). The response of the detectors is fast and reliable because of built-in self-check systems. Sources of false alarms can be avoided by various filtering and signal processing schemes. More information on optical detectors is presented in Section IV.

## E. AGENTS

The selection of the correct agent is critical to the automatic fire protection system for a hardened aircraft shelter. The likely fire incident is a JP-4 fuel spill/spray as a result of fueling operations. The resulting running pool of fuel may then be ignited accidentally, resulting in a running fire that could cover most of the HAS floor area, and possibly the entry ramp, within a few seconds. This type of fire scenario would immediately involve the aircraft, weapons, electrical panels, and other equipment critical to the mission of the shelter. The agent selected must be capable of rapid suppression, and should be clean and compatible with the HAS environment. In addition, the agent system selected should have three-dimensional characteristics with the ability to suppress indirectly accessible fires which might occur within the aircraft.

The HAS can be considered an open system because of: (1) the long closing time of the front door, (2) the airflow caused by ventilation air fans, and (3) the airflows caused by jet engines running and exhausting through the rear of the HAS. Water is not available at any shelter. No fire protection is required above the airplane/munitions heights because only two rows of explosion-proof housed lights exist on the upper metal-covered concrete arch. The agent selection should reflect the priority of the automatic fire protection system, which is to keep the aircraft systems mission-ready.

With the above criteria in mind, existing agents were evaluated for their use in the automatic fire protection system for HAS. The agents evaluated included foams, dry chemicals, halons, and "exotic" agents (halon-aspirated foams, halofoams, gels, etc.). The capabilities of these agents, as they relate to the HAS FPS, were evaluated and are discussed in the following paragraphs. Reference 1 provides additional information about agents.

1. Foams

The firefighting capability of foams (AFFF) is based on their ability to blanket the fuel surface, thereby, prohibiting interaction of the fuel with oxygen. Foams are considered to be one-dimensional agents and show poor firefighting performance against a running fuel fire where the fuel may run out from under the foam blanket and reignite. Foams are also 94-97 percent water, which gives them no Class C capabilities and results in problems with equipment freezing if they are stored at low temperatures. In addition, the lack of water at these shelters makes the production of foams from concentrate impractical. This means that the large volume of foam necessary to extinguish a fire would have to be stored as a premixed solution with antifreeze, making necessary the installation of exterior hardened tanks and plumbing. Finally, foams are considered dirty agents around operational aircraft. All of these considerations make foam an inappropriate first-line agent in the fire protection system for HAS.

2. Dry Chemical Agents

Dry chemical agents are categorized as heterogeneous chemical fire extinguishants. These powdered salts are, for the most part, salts of the alkali metals and ammonia. These agents extinguish fire by inhibiting chemical reactions necessary to combustion through a variety of mechanisms. In general, dry chemical agents have been shown to be effective fire-extinguishing agents with quick action, Class BC rating and fairly good three-dimensional characteristics. Associated with dry chemical agents are problems with poor throw range, poor performance in high-airflow conditions, corrosion, cleanup, and visibility. Because dry chemical agents are considered dirty agents with high cleanup costs, they will not be further considered for use in the HAS.

3. Carbon Dioxide

Carbon dioxide ($CO_2$) extinguishes fires primarily by diluting the oxygen necessary for combustion to a point at which combustion can no longer take place. This agent is expelled as a gas and has good three-dimensional capabilities, as well as a BC rating. Problems associated with it are poor

throw range, low-temperature hazards (it is expelled at a temperature of -76 °C), and poor performance in nonquiescent conditions. The poor performance in nonquiescent conditions and the high concentrations of agent necessary for extinguishment (25 percent) make carbon dioxide unacceptable for application in the HAS.

4. Halons

Halons are in the general class of homogeneous fire suppressants. Their means of extinguishment is the competitive inhibition of free radical chain-branching reactions in combustion sequences. Halons are halogenated hydrocarbons of the Freon family, of which only three are in common use as extinguishing agents: Halon 1301, Halon 1211, and Halon 2402. Halons are excellent BC agents because they are clean and efficient and possess good three-dimensional characteristics. The physical characteristics of each of these compounds have much to do with their fire-extinguishing capabilities.

Halon 1301 is expelled as a gas and mixes well with air, making it extremely effective in enclosed spaces. Because Halon 1301 is a gas, it is subject to effects of drafts and therefore is inefficient for use in a large open system or in a partial flooding application (such as exists in a HAS). It is, however, quite effective in total flooding situations.

Halon 1211 is expelled predominantly as a liquid and quickly becomes gaseous. Because of its liquid component, Halon 1211 has some flame plume penetration ability, and throw directionality. Although the range of throw is limited, Halon 1211 is currently the primary auxiliary agent aboard aircraft crash rescue vehicles because of its cleanness and low toxicity. Since Halon 1211 has some direction of throw and since it is heavier than air (therefore, the agent concentration tends to stratify), this agent is a good choice for use in a partial flooding application such as HAS. A comparison of Halon 1301 and Halon 1211 HAS systems is shown in Table 1.

Halon 2402 is expelled as a liquid with a boiling point of 117 °F and stays liquid until it is within the fire zone. This characteristic gives Halon 2402 good throw range and direction. Halon 2402 will penetrate the flame front and even the fuel surface, temporarily making the fuel inert.

TABLE 1. COMPARISON OF HALON 1301 AND HALON 1211 HAS SYSTEMS.

| Parameter | Halon 1301 HAS System | Halon 1211 HAS System |
|---|---|---|
| Halon agent (assuming test shelter 70 °F) at boiling point | -75 °F | +25 °F |
| Change in temperature of agent to ambient (70 °F) | 145 °F | 45 °F |
| $H_2O$ cloud | Dense | Dense |
| Form out nozzle | Gas | 80 percent liquid |
| Throw pressure for 45 feet | 720 lb/in.$^2$ | 360 lb/in.$^2$ |
| Thrust hazard | Yes | Less |
| Throw range without fire | Moderate | Good |
| Throw range with fire | Poor | Good |
| Nozzle pattern | Narrow (required to throw gas) | Wide (liquid/gas) |
| Expected decomposition | Moderate | Low |
| Toxicity (neat agent) | Low; 7-10 percent for 1 minute; no effects | Medium; 4-5 percent for 1 minute; no effects |
| Tanks | High pressure | Medium pressure |
| Frostbite | Moderate | Low |
| Modular | Yes; many tanks, additional mounts | Yes; fewer tanks, fewer mounts |
| Agent in wind | Not effective in crosswind | More effective |
| Fire systems | No bids for 1301 | All bids for 1211 |

This means it provides less danger of flashback and more efficiency in an outdoor environment than either 1211 or 1301. Halon 2402 has an increased toxicity level which needs further definition before this agent can be considered acceptable for general use or in a semienclosed environment. In addition, there is a lack of state-of-the-art technology regarding such features as nozzle design, application rates, etc. These considerations eliminated the use of 2402 for application in the HAS fire protection system.

5. "Exotic" Agents

The use of "exotic" agents such as halon foams, halon-entrained foams, thiotropically gelled dry chemicals, and halon mixtures for the HAS fire protection system was eliminated. These agents are in the developmental stage and their performance is not completely defined.

6. Summary of Agents Considered

As a result of the above evaluation of existing agents, it was decided that the use of Halon 1211 in the automatic fire protection system for HAS represented the best available technology. The physical properties of Halon 1211 are given in Table 2.

TABLE 2. PHYSICAL PROPERTIES OF HALON 1211.

| | |
|---|---|
| Chemical name | Bromochlorodifluoromethane ($CF_2ClBr$) |
| Boiling point (at 1 atmosphere) | 26.0 °F (-3.3 °C) |
| Freezing point | -256.0 °F (-160.5 °C) |
| Molecular weight | 165.4 |
| Heat of vaporization (at boiling point) | 57.0 BTU/lb |
| Vapor density at 70 °F | 0.444 lb/ft$^3$ |
| Liquid density at 70 °F | 104.0 lb/ft$^3$ |
| Vapor pressure at 70 °F | 40 lb/in.$^2$ absolute |
| Vapor pressure at 120 °F | 90 lb/in.$^2$ absolute |
| Critical temperature | 309 °F (153.8 °C) |
| Critical pressure | 595.4 lb/in.$^2$ |
| Critical density | 44.5 lb/in.$^2$ absolute |

This choice was based on the fact that Halon 1211:

a. Is a clean agent around operational aircraft,

b. Has a class BC rating,

c. Possesses good three-dimensional characteristics,

d. Has sufficient throw and direction to be used in an open system,

e. Is an efficient agent which will extinguish a fire rapidly, and

f. Has an acceptable toxicity.

7. Agent Application

As part of the fire protection system for HAS, the application strategy for the optimum agent was considered. The major factors considered in the application of the Halon 1211 included the following:

a. The HAS is an open environment which may be subject to high airflow conditions,

b. A sufficient concentration of agent must be maintained in the HAS to ensure the extinguishment of all anticipated fires and the inhibition of flashback,

c. The agent must be used in such a way as to maximize its economy and efficiency.

To further assess agent needs, a calculation was made of the halon concentrations at various protection heights. The results of this calculation for the two-thirds-length, third generation hardened aircraft shelter at Tyndall AFB, Florida are shown in Table 3. The values given represent the maximum calculated concentrations for a 3200-pound dump of Halon 1211 assuming (1) ideal gas behavior, (2) no ventilation losses, and (3) no halon concentration above the protection height.

TABLE 3. MAXIMUM CALCULATED CONCENTRATIONS FOR 3200-POUND HALON 1211 DUMP.

| Protection height, ft | Approximate internal volume $ft^3$ | Maximum concentration, % at 70° C |
|---|---|---|
| 14 | 88,386 | 7.52 |
| 19 | 113,599 | 5.95 |
| Full shelter | 147,016 | 4.67 |

Evaluating the results contained in Table 3 and considering that all of the critical protection areas in the HAS are located below 14 feet (tail height) showed that a partial flooding technique represented the most economical and efficient use of agent. This technique was considered viable because Halon 1211: (1) is denser than air and will naturally maintain its highest concentrations at the bottom of the shelter, and (2) is expelled predominantly as a liquid with a good direction of throw.

Several methods of obtaining an inert atmosphere inside the shelter for a sufficient period to ensure extinguishment of all fires were considered. Among these were:

a. Use of a greater amount of agent than that specified in NFPA 12B for Halon 1211. This amount would compensate for ventilation losses and the presence of halon above the protection height.

b. Placement of additional bottles at the front door so that, as these bottles discharge, the airflow created by their discharge pattern lessens the severity of wind effect and ventilation losses through the front door. This effect could be maintained by increasing the discharge time.

c. Use of two different-sized bottles in a modular system. The larger bottles would have up to double the discharge time, thus maintaining the agent concentration for a longer time.

d. Directing of additional halon toward the engine nacelles of the aircraft to extinguish this potential internal fire source.

8. Halon Toxicity

When selecting an agent for the HAS project, the toxicity of the agent was of major concern. Because the halons are clean agents and leave a minimum amount of residue, they are prime candidates for the HAS environment. However, they do have toxic properties that may pose a threat to personnel inside the shelter. Halon 1301 is the least toxic of the halons and is considered relatively safe if used properly. National Fire Protection Association (NFPA) Standard 12A gives the maximum safe exposures to the neat agent for man as 7-10 percent for 1 minute. The reported average concentration to produce lethality in test animals is 832,000 ppm (83.2 percent). The NFPA standard states that undecomposed Halon 1301 produces minimal central nervous system effects at concentrations under 7 percent. Exposure at 7 percent and 10 percent for a few minutes produced dizziness, impaired coordination, and reduced mental acuity. At exposures greater than 10 percent, these effects increased in intensity. The NFPA Standard also states that even in somewhat prolonged exposures, where these effects are noted, recovery is rapid and complete when the victims are provided fresh air.

Halon 2402 has been shown to be significantly more toxic than Halon 1301 and 1211. In fact, 126,000 ppm (12.6 percent) is the reported average lethal concentration (ALC). The NFPA standard states that exposure for minutes at 2000 ppm (0.2 percent) or 60 minutes at 1000 ppm (0.1 percent) produces central nervous system effects. Fresh air exposure after the symptoms appear will usually induce recovery with no long-term effects.

Halon 1211, which was chosen as the agent in the HAS environment, is more toxic than Halon 1301 but less toxic than Halon 2402. The reported ALC for 1211 is 324,000 ppm (32.4 percent), and the safe exposure limits are 4-5 percent for 1 minute. The NFPA standard for Halon 1211 states that exposure below 4 percent for 1 minute or less has no effect on the central nervous system. Dizziness, impaired coordination, and reduced mental acuity become definite after concentration levels reach above 4 percent for longer durations. When the levels reach 5-10 percent there is a risk of unconsciousness or possible death if exposure is longer than 1 minute. The report also states that Halon 1211 apparently does not remain or accumulate in the body, so removal of exposed personnel to fresh air induces rapid recovery.

Decomposition products from Halon 1211 can also pose a problem for personnel and equipment found in the shelters. These products include HF, HBr, HCl, $Br_2$, $F_2$, $Cl_2$, and carbonyl halides. All of these compounds have very high toxicities; however, they also have high warning properties so that personnel are aware of their presence before levels that would cause a hazard are reached. The amounts of these products are reduced by more rapid discharge at the earliest stage of fire progress. In a typical fire situation, the heat and smoke would be so great that personnel could not remain in the area; therefore, the levels of decomposition products are not expected to reach a toxic level while personnel are present. However, if personnel are restricted in a space and are protected from smoke by a mask, that mask must be evaluated for transmission of fire product gases. While all agents have some toxicity associated with them, the agent chosen had to put out the fire in the required period of time and have an acceptable level of toxicity. For additional information on halon toxicity, see Reference 2.

## 9. Agent Distribution Systems

Three types of extinguishing agent delivery systems were considered for the HAS. The "Manifold System" consists of two dry pipe headers running the length of the shelter. Both of the headers are fed, either at the center of the header, or from one end. Nozzles are attached to the header at strategic locations to direct the agent release. The agent is stored in bottles at a single location. The bottles could be hung from the shelter ceiling so that they would be protected and out of the way. The disadvantage of this arrangement is that because the bottles would be quite heavy (6000 pounds) and large, vibration levels in the shelter could result in structural damage. Also, the large size of the suppressant bottles could obstruct the high tail sections of some aircraft. Finally, maintenance of the bottles would be difficult if they were to be hung from the shelter ceiling. Special equipment would be necessary to install and service the bottles. Another potential storage location for the agent bottles is in a hardened structure outside the HAS. This solves storage problems resulting from the large size and weight of the bottles; however, this solution would be very expensive to implement.

Another type of delivery system is the "Modified Manifold" system. This system consists of short runs of pipe to which several nozzles are

attached. Several of these modified manifolds would be strategically located in a shelter. Each short header is supplied with agent via its own tank, which is located adjacent to the header.

A similar method of delivering the extinguishing agent is a "Modular System," which does not employ a header system at all. The nozzles used to administer the extinguishing agent are attached directly to the agent tank. This eliminates pressure and time losses that might be caused by an elaborate plumbing system.

Both the modified manifold and the modular systems have the advantage of being small enough that they can be tailored to various size shelters. The modular system is somewhat more flexible than the modified manifold systems.

10. Nozzles

Several schemes were considered for the agent nozzle locations. The possibilities were to: (1) have nozzles suspended from the ceiling, (2) have nozzles pop up from the floor of the shelter, and (3) have nozzles mounted on the wall. Nozzles hanging from the ceiling of the shelter could obstruct the high tail section of the aircraft. Also, if a fire were to occur under an aircraft, agent discharged from the ceiling would have to counteract the fire buoyancy and would be obstructed by the airframe. Pop-up nozzles in the floor of the shelter could be obstructed by a vehicle, aircraft wheel, or debris. [illegible] they would be expensive to install because sections of the floors of existing shelters would have to be cut and replaced.

Locating nozzles on the walls of the shelters appeared to be the best solution. The installation costs would be minimized because no major modification to the shelter would be required; the extinguishing agent could be administered to fires under an aircraft; and the nozzles would not interfere with the operations taking place in the shelter. However, nozzles on the wall of the shelter would be required to throw the extinguishing agent a greater distance than nozzles mounted either in the ceiling or in the floor.

The width of the HAS is approximately 80 feet. Consequently, the maximum effective throw range of the extinguishing system mounted on the wall

of the shelter must be nominally 40-45 feet. However, the extinguishing system would also be required to arrest fires much closer than 40 feet. To administer the halon, multiple types of nozzles might be required, some to reach fires a long distance away and others to extinguish close fires (10-15 feet) in an efficient manner. All nozzles are required to provide good agent penetration to minimize halon decomposition.

11. Tanks and Seals

Some of the major factors ensuring the system reliability involve the integrity of the agent tanks and seals. Any mechanical seal can leak, especially when subjected to very high pressure and pressure gradients. The high vibration encountered within the HAS would aggravate any leak situation. This makes periodic maintenance and inspection of the agent storage apparatus essential to the effective operation of the extinguishing system within the HAS.

Several methods are available to monitor the contents of a pressurized cylinder. One is to monitor the pressure via a mechanical or electrical sensor in conjunction with monitoring the ambient temperature. A problem inherent with this type of system originates in the mechanical or electrical interface between the inside of the cylinder and the ambient condition. Because these junctions are not necessarily hermetic, they are a potential source of leaks.

A much more labor-intensive method of determining the amount of agent in a pressurized bottle is to weigh the bottle. Fluid levels in cylinders can also be monitored through the use of special radioactive or ultrasonic devices.

Another method ensuring the integrity of the contents of the bottles is to hermetically seal the bottles, thus, eliminating the mechanical interfaces where leaks are most likely to occur. Maintenance of the tankage system would be minimized because of the decreased potential for system leaks.

## F. SHELTER EVACUATION

The primary purpose of the fire protection system is to save the lives of the personnel and to minimize property losses in a shelter when a major fuel-spill fire occurs. Personnel protection can only be accomplished if the personnel inside the shelter escape safely. However, this may not be possible if special provisions are not made to expedite the egress from the facility.

When a full halon dump on a fire takes place inside a HAS, several things happen which would inhibit the egress of personnel from the shelter. First, when the halon is discharged, the air temperature inside the shelter drops dramatically due to the refrigeration effects of the liquid-vaporizing agent. This results in moisture precipitating out of the air in the form of thick clouds which block visibility and the facility lighting. Second, the combustion products produced by the extinguishing action of the halon include a thick black smoke which is toxic and blocks light, thus inhibiting the egress of the shelter personnel. Also, fuel vapors and combustion/pyrolysis products are toxic.

For these reasons, an escape system must be installed in the shelter to facilitate evacuation in the event of a halon dump. An escape system should be developed which will allow personnel to leave the shelters safely. Additionally, a washdown system for fuel should be made available.

SECTION V

# OPTICAL FIRE DETECTOR (OFD) INVESTIGATION AND TEST

## A. OVERVIEW OF DETECTORS

A HAS FPS must have a reliable fire detection device to sense the flame in its incipient state. Many of these devices are on the market today, and they can be grouped into two basic detection technologies, IR and UV. The two technologies can then be combined in any configuration, for example IR, IR-IR, UV-IR, UV, UV-IR-UV. The advantage of multiwavelength detectors is a reduced likelihood of false alarm.

## B. UV DETECTORS

Over the years there have been many advances in the techniques used to detect fires. UV detectors were among the first types of fire detectors employed in an industrial environment. The UV radiation emitted by most fires is quite strong and easy to detect with a sensor known as a Geiger-Muller (GM) tube. The wavelength of UV radiation, being relatively short, is absorbed by most media such as air, glass, smoke, dust, and Plexiglas, causing false signals that do not originate from the protected area to be eliminated. The disadvantage associated with this characteristic of UV radiation is that the UV detector may not be able to detect fire caused by smoke obscuration, or the UV intensity may be reduced by a buildup of dirt or oil on the lens. In an industrial environment, UV detectors are not subject to as many possible sources of false alarms as are IR detectors. The primary sources of false alarms to the UV flame detector in an industrial environment are arc welding and X-rays. Several techniques have been developed to permit the use of UV detectors in an environment where welding occurs. These techniques include the requirement of multiple detectors to see a fire, or signal cancellation schemes. However, there is no generic solution to fit all situations using only the UV detector. It is generally agreed that single-channel UV detectors should not be used exclusively where activities such as welding or X-raying occur.

UV detectors which use a GM tube are generally designed to respond to UV radiation with wavelengths from 0.18 to 0.25 μ. Most fires produce a great

deal of UV radiation in this range. The sun also produces UV radiation in this range; however, most of it is absorbed by the atmosphere before reaching the earth (see Figures 4 and 5).

Radiation is emitted in small bundles called photons. The energy of a photon depends on the wavelength of the radiation. When a photon strikes a metal plate such as a cathode (negatively charged plate), the energy of the photon is imparted to an electron within the plate, causing it to leave the surface of the cathode and be drawn towards the anode (positively charge plate). The energy that the electron must have to leave the metal plate is called the work function of the metal.

The operating envelope of a UV detector is a function of (1) the metal used for the cathode, and (2) the crystal housing of the detector. The metal most commonly used for the detector cathode is tungsten. Tungsten has a work function that will not allow an electron to leave its surface unless imparted with the energy from a photon with a wavelength shorter than 0.245 μ (see Figure 2).

The crystal most commonly used for the GM tube housing is quartz. Quartz is opaque to radiation with a wavelength shorter than 0.185 μ. Consequently, the operating envelope of the GM tube in the UV detector lies between 0.185 and 0.245 μ. The GM tube is the "heart" of the UV detector and its exact components and method of construction are closely guarded industrial secrets. There is a great deal of ongoing industry research to improve the performance of GM tubes.

The area between the cathode and the anode is filled with an ionizable gas. When an electron is emitted from the cathode and is rapidly being drawn toward the anode, it strikes a gas molecule with enough energy to cause electrons to be emitted from the gas molecule. The electrons in turn strike other molecules which release electrons. The total number of electrons emitted in this manner is several million times more than were emitted from the cathode (see Figure 6). When this chain reaction takes place, a current between the cathode and anode can be measured. The current flow can be stopped in two ways: (1) by removing the applied voltage between the cathode and anode, or (2) by reversing the charge on the cathode and anode. There are

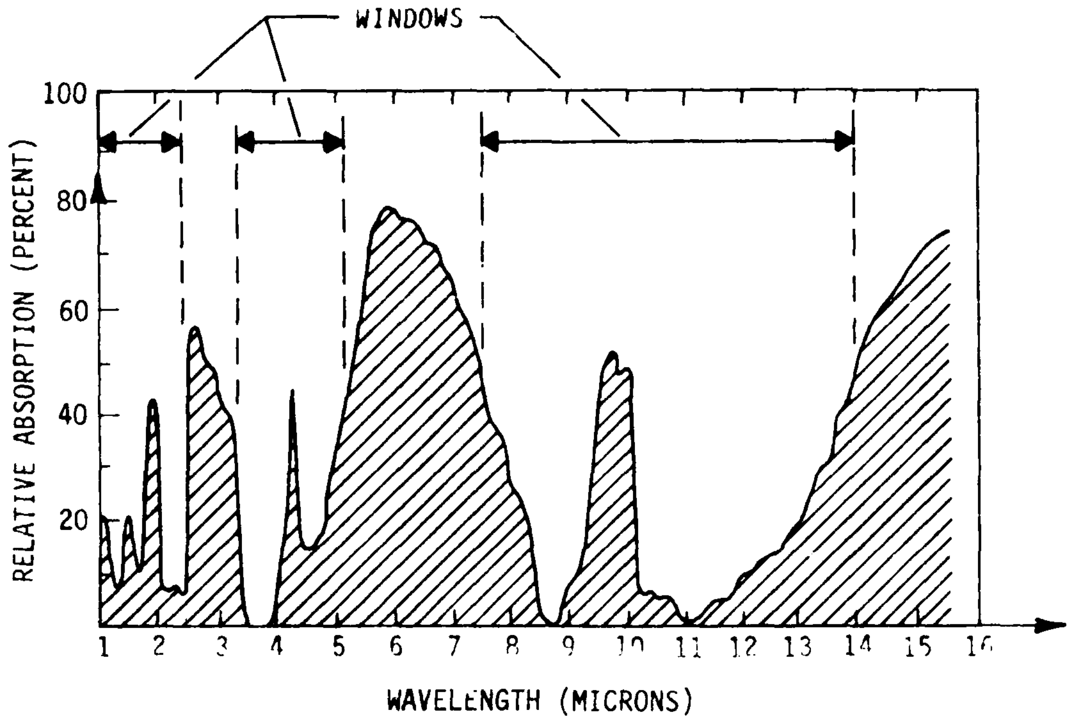



Figure 4. Atmospheric Absorption.

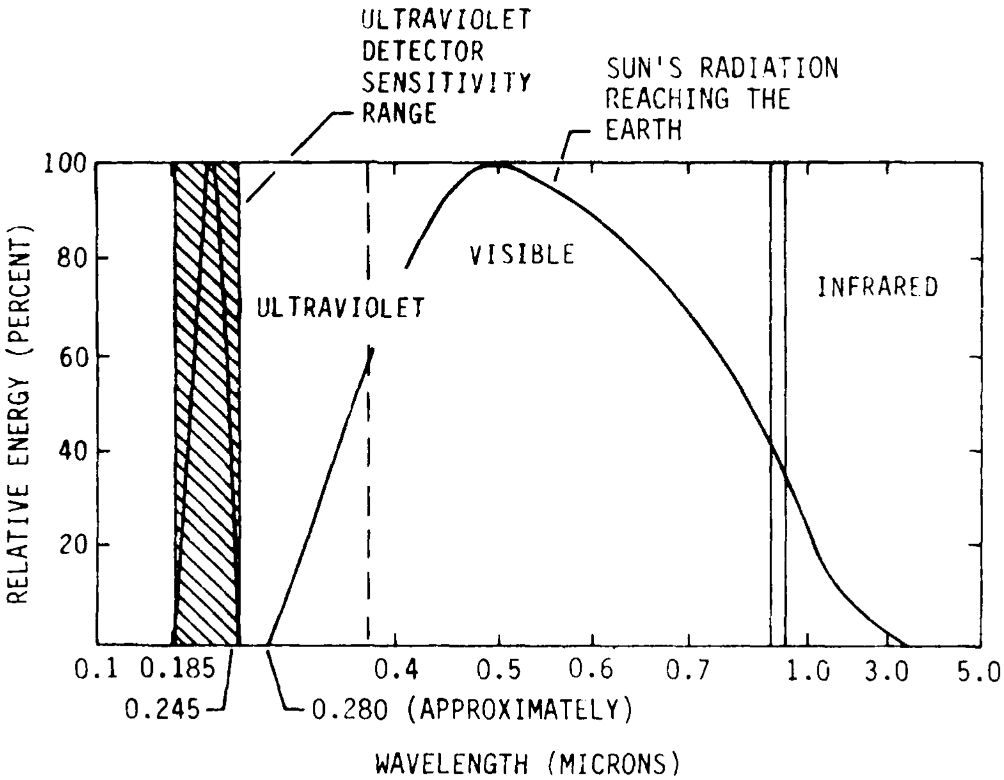



Figure 5. UV Detector Range and Radiation from the Sun.

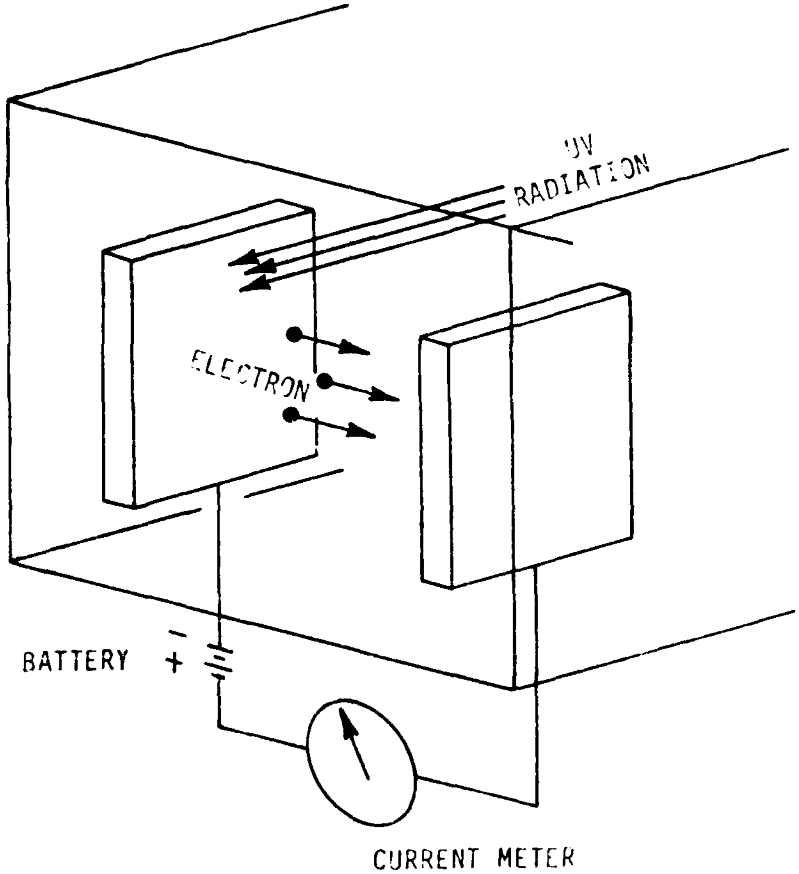



Figure 6. Geiger-Mueller Detector.

varying opinions on what is necessary to stop the current flow between the terminals. The current is usually allowed to flow for a very short time before measures are taken to stop it.

The output of a GM tube is generally a voltage pulse. The intensity of the UV radiation striking the detector is proportional to the frequency of the pulses. This is analogous to a switch that is normally open. When UV radiation strikes the detector, the switch is momentarily closed. The frequency with which the switch is opened and closed is proportional to the intensity of the UV radiation striking the detector.

UV radiation is generally thought of as that radiation with a wavelength between 0.10 and 0.40 μ (see Figure 5). There are a number of

sources that produce UV radiation, the most common natural sources being the sun and lightning. Both of these are rich sources of this radiation, and are common in the workplace.

Other sources of UV radiation include any kind of electrical sparking such as arc welding or mercury vapor lamps, and flames such as those produced by an acetylene torch, a cigarette lighter, or a JP-4 fuel fire.

Because the wavelength of UV radiation is relatively short, the radiation is easily absorbed by substances such as glass, smoke, air, and a number of vapors not normally found in quantity in a HAS.

The absorbency of UV radiation by many types of media reduces the likelihood of a UV flame detector responding to false signals. However, a fire that produces an abundance of smoke prior to a flame is more likely to go undetected. Additionally, a light film of oil or dirt on the lens of the UV detector can filter the incoming radiation to the point where the detector does not respond to a small fire. In many situations, the likelihood of lens contamination is not considered a problem. However, in environments where it is a problem, action has been taken to ensure that the viewing lens remains clean. One method that has been proven to be quite effective involves blowing clean, dry air or nitrogen over the face of the lens. Another innovative idea is to thermally clean optical surfaces. This latter approach has been used in space vehicles.

Because the problem of lens contamination is so critical to the reliability of the UV detector, most UV detectors are equipped with a self-testing mechanism. This generally consists of a UV lamp situated so that, when pulsed, it can be seen by the UV detector through the lens. The signal strength of the test signal is compared to a reference signal. When the test signal falls below an acceptable level, a warning alarm is set off.

As previously mentioned, UV detectors are susceptible to false alarms from intense UV sources such as arc welding or malfunctioning mercury vapor lights. Additionally, reflections of UV radiation are much more difficult to contain. This has necessitated innovative techniques to reduce the probability of false alarms. Some of the more applicable methods are discussed in this report under the heading "Dual-Channel UV/IR Detectors."

## C. IR DETECTORS

In addition to UV radiation, fires also produce IR radiation. Its longer wavelength allows IR radiation to penetrate smoke and other substances which absorb UV radiation. However, sources of IR radiation are not limited to fire, but include all masses that contain heat. The "radiational cooling" of the earth, often referred to by meteorologists, is an example of IR radiation. The sun is extremely rich in this type of radiation. Another very common source of IR radiation is electrical radiant heaters. These "hot mass" IR sources are referred to as "blackbody heat" or "blackbodies." Because there are so many sources of IR in the industrial setting, the number of false alarms caused by detection of nonfire sources has precluded the use of a simple single-channel IR sensor. To make the basic IR detector function in the industrial environment, additional discrimination functions must be added.

An important characteristic of the IR radiation originating from a fire is the low-frequency AC component or "flicker." IR radiation originating from a stationary black or hot body or the sun is much more continuous. The presence of "flicker" has been used quite successfully to identify fires. However, shimmering reflections, slowly turning fans, moving IR sources, and flickering lights can still activate the detector.

A significant advancement in IR detectors has been the development of sensors that can react to specific bands of IR radiation. One band of specific interest to IR flame detectors lies between 4.1 and 4.6 μ (centered at 4.4 μ). Two significant characteristics are associated with this band of radiation. First, hydrocarbon fires produce a "carbon dioxide spike" in this region (Figure 7). Second, IR radiation in this region from the sun is absorbed by the atmosphere (Figure 4). Consequently, IR sensors can be manufactured to operate in this "quiet" region of the IR spectrum with a very low signal-to-noise ratio. The detector is still subject to false alarms from blackbody radiation such as the hot tail section of an aircraft, but to a far less extent than broadband IR detectors.

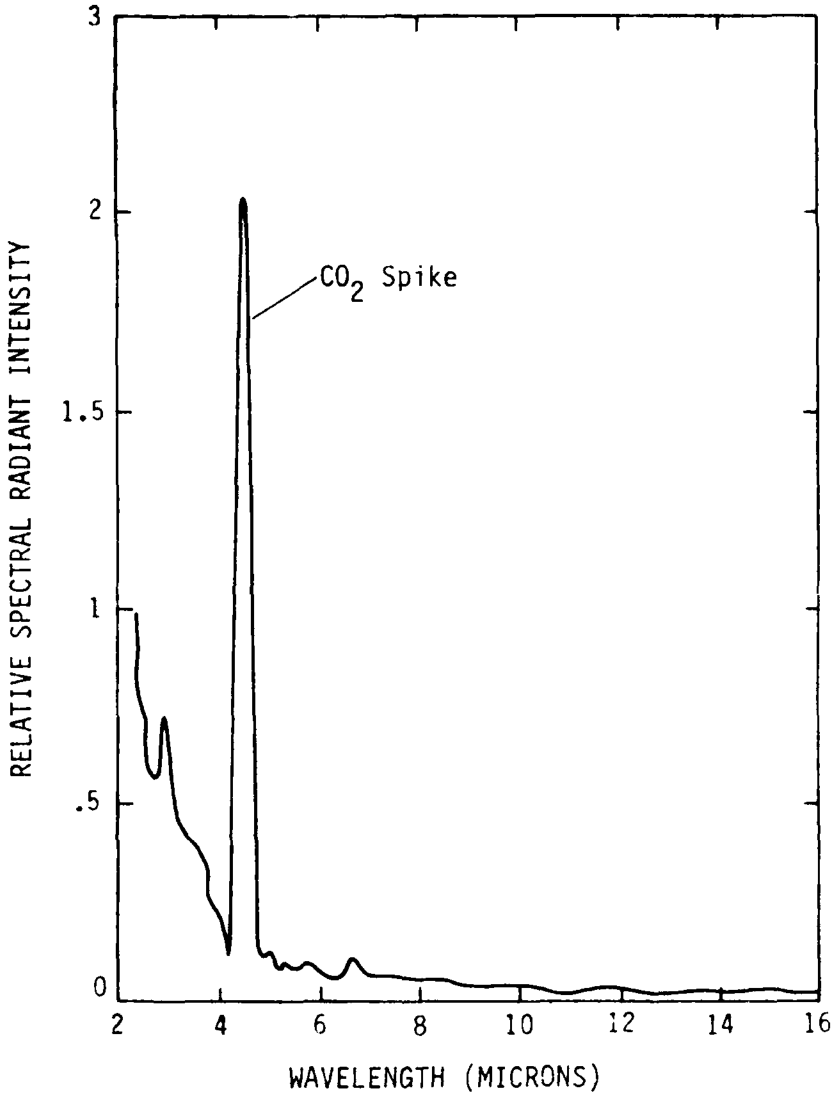



Figure 7. Infrared Emission Spectrum of a JP-4 Fire.

A new type of dual-spectrum flame detector uses two bands of IR radiation. This technology is rather new and is considered proprietary by the manufacturers of these detectors; however, the basic principles associated with dual-band IR fire detection are well understood.

There are two basic types of sensors used in the IR flame detector: the thermopile and the pyroelectric sensor. The thermopile sensor is analogous to a number of thermocouples connected in series. As the number of connections or thermocouples is increased, the sensitivity of the device increases proportionally. With the current level of microchip technology, it is possible to put many thermocouple connections on a single chip. While these devices are quite sensitive to impinging radiation from a fire, they are also quite sensitive to rapid changes in the ambient temperature.

The pyroelectric detector operates on a much different principle from that of the thermopile detector. The output of the pyroelectric detector depends on the time rate of change in the detector temperature rather than on the detector temperature itself. It is constructed of a pyroelectric crystal such as lithium tantalate or ceramic barium titanate. When these crystals are exposed to a thermal gradient, they produce a current. The pyroelectric crystal is a dielectric that will also produce spurious outputs when subjected to mechanical shock or vibration, much like a piezoelectric crystal produces a current flow when exposed to a transient pressure gradient.

As previously mentioned, IR radiation is prevalent in the workplace. Any hot object will produce IR radiation. A large amount of IR radiation is produced by the sun. However, not all the radiation emitted by the sun reaches the earth. The earth's atmosphere absorbs a portion of this radiation, as shown in Figure 4. Several bands within the IR spectrum are not saturated with the radiation from the sun. These quiet areas or "windows" within the IR spectrum are centered at about 1.2, 4.4, and 11.1 μ. These windows have been used in a variety of ways by flame detector manufacturers.

The flicker or oscillating property of a fire is the result of the dynamic characteristics of a flame. If a fire is viewed at a very close range where the edge of the flame is not in the viewing window of the detector, there will not be much flicker associated with the fire. However, when a fire can be seen from an adequate distance, flicker in the range of 1-6 Hz is present. Because the response of both pyroelectric sensors and thermopile sensors is extremely fast, flicker can be used to distinguish fires from false alarm sources.

Flicker can be simulated by a number of activities such as moving or vibrating hot objects, or by chopping sources in front of a hot object such as a rotating fan placed in front of the hot tail section of an aircraft. Consequently, simple, single-sensor IR detectors have not been very successful in the workplace at discriminating between a fire and false alarm source. This has created a need for the dual IR detector.

## D. DUAL IR DETECTORS

The dual IR detector usually utilizes the mid-IR window (centered at 4.4 μ), as well as one of the other quiet windows in the IR spectrum. The window centered at 4.4 μ is particularly useful because almost every fire in the workplace produces carbon dioxide, which radiates at 4.4 μ (Figure 7). Exceptions to this are hydrogen and metal fires, which produce a broad band of very intense radiation. The information obtained from the two IR sensors can be processed in a number of ways; these are outlined below.

### 1. Flicker

The signals from both IR sensors are generally digitized and the frequency of those signals is determined. As previously mentioned, the flicker frequency of most fires is between 1 and 6 Hz. Most dual IR detectors do not alarm unless both signal frequencies lie within this range.

2. Time Rate of Change

IR radiation of all wavelengths is quite common in the workplace. Consequently, it is necessary to establish a background level of radiation. The background level must constantly be monitored and adjusted to compensate for the ambient conditions. Small fluctuations in this background radiation, even those of a proper flicker frequency, will not generally alarm the dual IR detector. However, rapid changes in the background radiation can indicate that a situation is quickly getting out of control. If the background level of radiation becomes too high, a fire will not be detected. This is referred to as saturation of the detector.

3. Flash

If a fire were to occur suddenly and engulf the fire detector, as would be the case in an explosion, immediate action on the part of the fire suppression system would be required. Some detectors are programmed to alarm at a certain level of background radiation, regardless of any of the other factors that may exist.

4. Signal Ratio

All fires have specific radiation signatures unique to the chemical reactions taking place. Hence, the strength of the signals from the two IR sensors can be used to check for specific signature properties. This is done by looking at the ratio of the two signals, a procedure which eliminates the problem of varying radiation intensities. The relative intensity of the radiation of the two wavelengths is generally maintained, regardless of the overall strength of the fire, when specific chemical reactions are taking place, such as the formation of carbon dioxide. This ratioing scheme can be upset by several circumstances. For instance, if an uneven layer of contamination is deposited on the lenses of the two sensors, the intensity of one signal will be degraded more than that of the other, thus, altering the signal ratios. If the layer of contamination on the lenses is even, but is of a nature to absorb IR radiation, this may also alter the signal ratio. Since water absorbs IR radiation, the signal ratio may be altered simply by the humidity in the air. To compensate for the many circumstances which may alter the signal ratio of

the two IR bands, detectors are usually programmed to alarm at a specific signal ratio within an adjustable tolerance.

### 5. Cross-Correlation

A fire may produce many types of radiation of varying wavelengths and amplitudes. However, the majority of the radiation emitted from a fire has the same flicker frequency. Some false alarm sources produce IR radiation of a sufficient amplitude and, under the proper circumstances, the right frequency to simulate a fire. However, they generally do not produce both bands of IR radiation with the proper amplitude and frequency characteristics. If the amplitude of both IR channels is high enough, and the frequency of the signals is within 1-6 Hz, the cross-correlation of the peaks and valleys of the two signals checks that both signals are being emitted from the same source. This helps eliminate the possibility of two unrelated IR signals alarming the detector.

### 6. Time Delays

IR detectors can detect the presence of a fire rapidly. However, this acute sensitivity inherently makes the detector system susceptible to false alarm signals that momentarily simulate a fire. Many detectors require a specific time period before they will alarm. In situations where the danger of an explosion is present, this time delay might be adjusted downward to be quite short. However, a longer time delay allows the detector more time to test and to distinguish between fires and false alarms. The damage done by a false dump of a suppression system often does much more harm and is more expensive than allowing a fire to burn a second or two longer.

## E. DUAL-CHANNEL UV/IR DETECTORS

Many false alarm sources for UV and IR detectors are mutually exclusive. This has led to the advent of dual-channel UV/IR detectors. These detectors can be made quite rugged. They have some of the same limitations of single-spectrum UV detectors; that is, they are somewhat blind to fires hidden by smoke, and are very sensitive to lens contamination.

The primary advantage of UV/IR detectors, as they relate to the HAS program, is that they do not alarm in response to chopped blackbody radiation. Second, they are less susceptible than dual IR detectors to false alarms around operational aircraft. The IR jamming device checkout, which is often completed in the HAS, is one false alarm source for dual IR detectors. Also, a UV/IR detector will not alarm due to sudden changes in temperature. The IR channel of the detector may become saturated and declare a fire, but the UV channel will not see anything, thus preventing the detector from alarming.

The UV channel and the IR channel of the detector are generally locked together electrically so that both sensors are required to alarm prior to the declaration of a fire by the detector. The flicker of an IR radiation source and the amplitude of the source are required to be within a specific range prior to alarming. The IR circuitry is constantly monitoring the background radiation, and adjusting to that. Here again, the detector can become saturated by the background radiation, thus rendering the detector blind to a fire.

The UV channel of the detector generally operates in the same fashion as a single-channel UV detector. It utilizes a GM tube and continuously monitors the incoming UV radiation.

The UV/IR detector can be programmed in a fashion similar to that of the dual IR detector. The concept of requiring a time delay prior to alarming is quite common. Some detectors can also be programmed to alarm given only an intense flash, regardless of the flicker component of the radiation source. A concept of fire identification utilized by most fire detection systems is commonly referred to as "voting." This concept requires a fire to be sensed by more than one detector prior to alarming the suppression system. No manufacturer will claim that their fire detector is 100 percent free of false alarms. For this to be generally accomplished, the sensitivity of the detector would have to be adjusted down to the point that not only will the detector ignore false alarm signals, but it will also ignore a genuine fire. Consequently, the detector would not accomplish the desired goal. "Voting" has proven to be effective in eliminating false alarm signals, and, at the same time, it provides prompt suppression response to a fire.

## F. OFD DESCRIPTION

The OFDs selected for testing by NMERI are described in Appendix G. For each, two categories of information are presented: General Description and Signal Processing Evaluation. Company tradenames for the detectors are not included; instead, the devices are designated by number (1-8). The general description of each detector is a combination of information supplied by each manufacturer and observations by NMERI research personnel. Quoted prices are approximate retail values for a single unit unless otherwise stated. The signal processing evaluation was conducted by Professor W. W. Granneman at the University of New Mexico Department of Electrical Engineering from schematic drawings supplied by each manufacturer. These evaluations are presented directly from Dr. Granneman's reports to NMERI, except where specific reference to a tradename appeared.

## G. OFD TESTING

The test program was conducted in two phases. An initial low-cost evaluation of the OFDs was made using a small-scale test program. The information and experience gained during this program were used to design and conduct large-scale test programs. The small-scale testing was conducted in the combustion laboratories at NMERI. The large-scale tests were conducted at the German Aircraft Shelter (GAS) on Kirtland Air Force Base and other similar locations. Use of the GAS allowed evaluation of the detectors in a lifelike environment and realistic geometry similar to that of the HAS.

Eleven different detectors were tested during this evaluation. Six UV/IR detectors were tested. Two of the UV/IR detectors were from the same manufacturer with the only difference being in sensitivity levels. The UV/IR detectors were labeled UV/IR 1-5. The two detectors from the same manufacturer were labeled UV/IR 1 and UV/IR 1S (the more sensitive detector). Three different IR/IR detectors were tested and were labeled IR/IR 1-3. One single-channel UV detector was tested and was labeled UV 1. There was also one detector with two UV channels and one IR channel which was labeled UV/UV/IR.

1. Small-scale Tests

The room used for the small-scale tests was approximately 15 feet by 15 feet. The OFDs were placed on a tripod with a swivel head. A 6-inch flickering propane flame from a Bunsen burner at the same height as the detector was used as a flame source. The parameters used to characterize the performance of the OFD during the small-scale test program were field of view (angle and distance) and response time. The tests conducted were:

| Test | Description |
|---|---|
| 1A | Flame directly in front of detector, room closed |
| 1B | Flame 90 degrees off axis from detector, room closed |
| 2A | Flame directly in front of detector, room open to introduce sunlight and outside air currents |
| 2B | Same as 2A with flame 90 degrees off axis |

Each test was repeated three times and the data were averaged. Taking three data points provided greater accuracy and lower uncertainty of casual occurrences. Information on each individual data point was recorded on data sheets.

The small-scale tests were conducted to allow NMERI to gain experience with each of the detectors in a low-cost environment. It was not possible for the low-cost evaluation to be conducted in a realistic environment; therefore, results are not directly applicable to this particular application.

No conclusions for the final application can be drawn from the performance of the detectors during the small-scale test because the fire was not similar to those which would be encountered in the HAS application. The experience gained during the small-scale test program allowed the design of a more effective evaluation of the detectors in the GAS-scale test program than would have been possible without it.

2. GAS-Scale Tests

The tests in the GAS-scale test series were conducted under conditions as close as possible to those that exist in the HAS. The test goals were to characterize the performance of the OFDs and their response to false alarm stimuli.

The tests were conducted inside a prototype GAS that was open on both ends. One of the ends was covered with a black plastic sheet to prevent winds from blowing through the shelter. The shelter is 24 feet 7 inches high and 48 feet 4 inches wide at the front (open) floor level. It is 72 feet 7 inches long. The floor rises 2 feet to a second level 33 feet 7 inches from the front opening. The detectors were located on the second level 1 foot from the first level. Unless otherwise stated, the detectors faced the side wall of the GAS during the tests.

3. FOV Performance Tests

The HAS application requires knowledge of the three-dimensional field of view (FOV) of the detectors. The FOV of each detector was mapped and plotted in two planes 90 degrees apart. Measurements in the first plane were made with the detector in the orientation recommended by the manufacturer. The detector was then turned 90 degrees for FOV mapping in the second plane. The FOV was mapped by determining how far away the OFD could see the test fire (up to a maximum of 35 feet) as a function of the angle between the axis of the detector and the fire. The fire pans were mounted near the side wall and the detectors were mounted directly across the shelter from the fire. Thus, all of the detectors were "looking" at fires with the wall of the shelter behind them. This was done to ensure that the fires were as nearly identical as possible, but it limited the maximum distance between the detectors and the fires to 35 feet.

During the FOV tests the detector was mounted on a tripod 3 feet above the ground. The field of view was mapped by starting with the fire 35 feet from the detector. The detector was rotated at 5-degree intervals in the horizontal plane and notations were made indicating if the OFD had detected the fire. The distance was decreased in 5-foot increments and the measurements repeated until the field of view was completely mapped in that plane.

Baseline tests were conducted with clean optics at room temperature. These tests were used as a baseline for the evaluation of performance degradation of the OFDs under nonideal conditions and are referred to as the clean series tests. Other tests conducted included performance evaluations with dirty optics, at a plane elevated relative to the fire and under hot and cold environmental conditions. During this test series, each OFD was mounted on a tripod and rotated at various angles relative to the test fire. The FOV was mapped only in the plane defined by the manufacturer's recommended orientation for all of the nonclean series tests.

These tests were conducted using 1 $ft^2$ and 4 $ft^2$ (2 ft by 2 ft) pan fires. The pans were 3.75 inches high with 1.5 to 2 inches of JP-4 floating on 1 inch of water. Water was used to allow the flame base to remain constant at the same level and to maintain the fuel at a constant temperature. These conditions ensured the same flame for all tests. The edge of the fire pan was 5 feet from the wall of the GAS, which had interior surfaces similar to those of all the HASs. The curved ceiling of the GAS was 14 to 15 feet above the pan. The fires were extinguished between tests by snuffing them out with a metal plate. Snuffing was used to extinguish the fires to keep any foreign materials out of the fuel which might change the character of the fire.

The 1 $ft^2$ and 4 $ft^2$ fires represented the two types of fires that might be seen by the OFDs. The 1 $ft^2$ fire is an optically thin fire, while the 4 $ft^2$ fire is optically thick. The detector would receive all of the radiation from an optically thin fire, whereas it would only receive the frontal portion of the radiation from an optically thick fire. As a fire grows (changes from optically thin to thick), the relative amount of UV radiation transmitted from the fire to the detector decreases. The amount of IR radiation from the fire increases as the fire grows. These changes are

caused by the fire changing to become more fuel-rich as it increases in size. Therefore, the absolute intensities and the ratio of UV to IR radiation are different for optically thick and thin fires and change continuously as a fire grows.

Data sheets were used to record whether or not the OFD detected the fire at each test point. Each data point was repeated three times and averaged during the entire GAS-scale test series.

Another consideration for the performance tests was response time. The statement of work for this project required that the fire protection system detect and suppress a fire within 30 seconds. A decision was made to divide the amount of time available for each action equally, that is, to allow 15 seconds each for detection and suppression. Thus, if any detector did not detect a fire within 15 seconds it was evaluated as if it had not seen the fire.

A shutter technique was used to test the OFDs. A 1.5 $ft^2$ by 2-inch-thick piece of grey foam was placed 2 to 3 inches in front of the OFD. The OFD was then reset to the ready condition. The foam piece was rapidly removed from in front of the OFD and the detector response time was determined. Time zero was defined as the moment when the shutter was displaced from the view of the OFD.

4. Clean Test Series

The clean test series was conducted to determine the performance of the detectors under ideal conditions and was used as a baseline to compare with other tests conducted during the FOV test series. The clean test series is defined below.

| Test | Description |
| --- | --- |
| 1A1 | Detector in manufacturer's recommended installation position with a 1 $ft^2$ pan fire |
| 1B1 | Same as 1A1 except the detector was rotated 90 degrees relative to its longitudinal axis |

1A4 Same as 1A1 except with 4 $ft^2$ pan fire

1B4 Same as 1B1 except with 4 $ft^2$ pan fire

During the analysis the footprints for each detector were characterized three categories, 15-second response, 5-second response, and blind spot. Blind spot parameters were calculated if the detector had a blind spot. Blind spots were generally a result of saturation of the detector from fires close to it. Seven parameters are listed for each of the categories. They are:

| | |
|---|---|
| Area | The area of the footprint ($ft^2$) |
| Rmx | The maximum range at which the detector responds to the fire (up to 35 feet) (ft) |
| θmx | The maximum half angle at which the detector responds to the fire (degrees) |
| Rθmx | The maximum range at which the detector responds to the fire at the maximum half angle (ft) |
| Bmx | The maximum range at which the detector does not respond to the fire within the response envelope (ft) |
| βmx | The maximum half angle at which the detector does not respond to the fire within the response envelope (degrees) |
| Bβmx | The maximum range at which the detector does not respond to the fire at the maximum half angle for no response within the response envelope (ft) |

Figure 8 illustrates the definition of the terms used to characterize detector performance. Half angles were used to characterize the FOV angle, because the detectors did not all have footprints that were symmetric about the axis of the detector.

When this program began, it was felt that the detectors would have 15 seconds to respond to a fire in the HAS. This information was given to the detector manufacturers when NMERI requested detectors for evalutation. After the OFD characterization was completed and the full-scale fire suppression system tests began, it became apparent that the detectors would have to respond to a fire in 5 seconds or less. Since the response time for the detectors can be varied by adjusting the sensitivity and the increased sensitivity was not requested, the data for both the 5- and 15-second response times are presented.

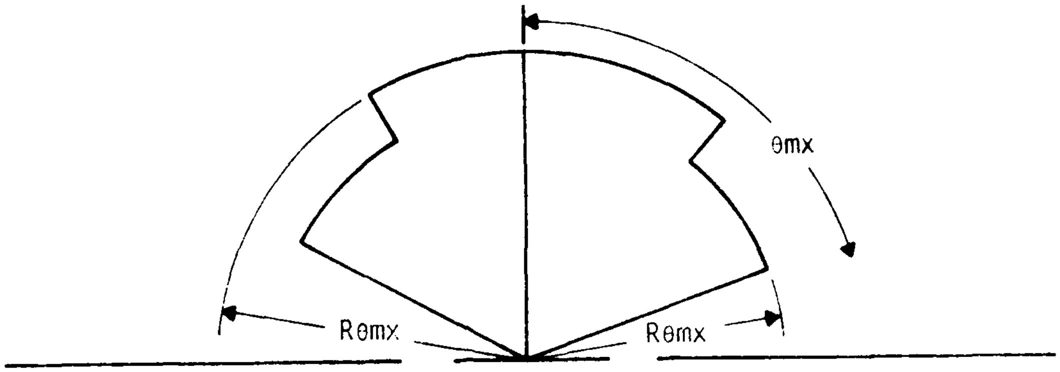
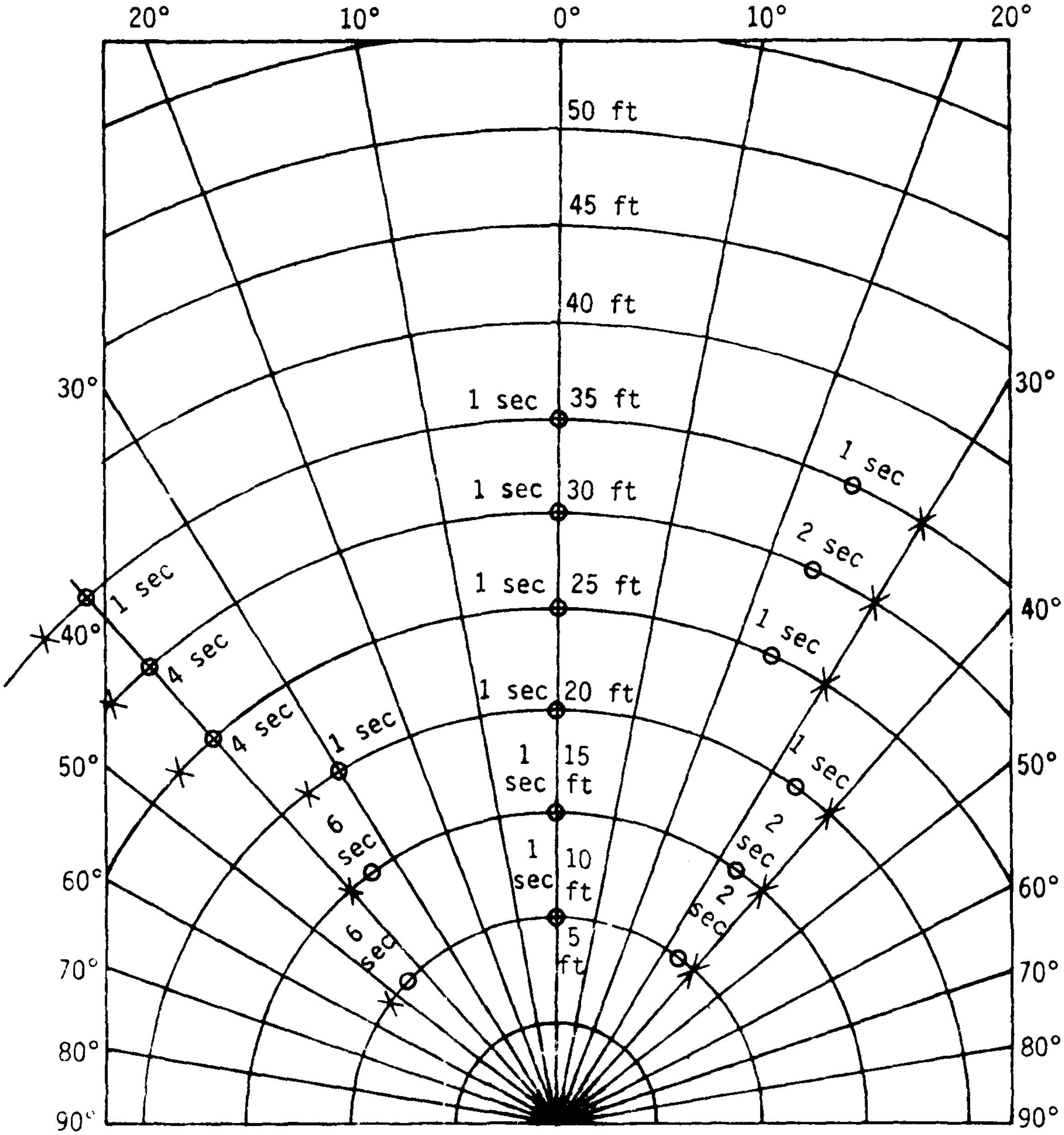



Figure 8. Illustration of Definition of Detector Evaluation Terms.

The data sheet showing the footprint for Detector UV/IR 1 for test 184 are shown in Figure 9. This typical data sheet shows that the response times have only been defined for the edges of the footprint and the axis of the detector. The response of each detector was measured at the intermediate points between those listed but was not recorded.

The areas of the footprints were calculated by summing the area subtended by each data point. The area was assumed to extend half of the distance between adjacent data points on the same radius and half of the distance to adjacent radii. At the inside surface the area was assumed to extend all the way to the detector, and at the outer surface the area was assumed to stop at the outer boundary. The fact that the response times were recorded only for the center and edges of the field of view has caused the calculated areas for the 5-second response times for some detectors to be unreasonably small. Unfortunately, this problem could not be corrected, because the UFD testing was completed before the 5-second response time requirement was discovered.




X = Not detected

O - Detected

Figure 9. Typical Data Sheet, UV/IR1, Test 1B4.

Tables 4 through 7 show the parameters used to characterize the footprints of each detector for each of the clean series tests. The area of the 15-second footprints varies from 294 to 3859 ft$^2$. The maximum half angles range from 35 to 180 degrees. Detector IR/IR 1 could not respond to the 1 ft$^2$ fires more than 25 feet away, and Detector UV/IR 3 did not respond to fires more than 25 feet away on Test 1A1. Detectors UV/IR 5 and UV/UV/IR had 360-degree fields of view for almost all of the tests.

The 5-second response footprint areas ranged from 0 to 3064 ft$^2$. Detector UV 1 was unable to respond to any of the fires within 5 seconds. The maximum half-angles range from 0 to 180 degrees. Once again, Detectors UV/IR 3 and IR/IR 1 could not respond to fires out to the 35-foot maximum. On test 1A4 Detector IR/IR 3 responded to fires only out to a range of 30 feet. The 5-second response footprint for Detector UV/IR 2 was the same size as the 15-second response footprint for all of the fires except one. All other detectors suffered varying degrees of loss of footprint area for the 5-second response, with the greatest loss generally occurring for the 1 ft$^2$ fires.

Detectors UV/IR 5 and UV/UV/IR apparently have the ability to see behind themselves, judging from their 360-degree field of view. This was a result of the detectors seeing reflections off the back and side walls of the shelter. [illegible] none of the other detectors saw these reflections, one can draw the conclusion that these two detectors [illegible] than any of the others [illegible].

[illegible] UV/IR [illegible] with different [illegible] the [illegible] saturated, [illegible] Detector UV [illegible] 1. The [illegible] saturated in [illegible]

[illegible]

TABLE 4. DETECTOR FOOTPRINT PARAMETERS, TEST 1A1.

| Type of detector | 15-Second response | | | | 5-Second response | | | | Blind spot | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Area, $ft^2$ | Rmx, ft | θmx, deg | Rθmx, ft | Area, $ft^2$ | Rmx, ft | θmx, deg | Rθmx, ft | Area, $ft^2$ | Bmx, ft | βmx, deg | Rβmx, ft |
| UV/IR 1 | 715 | 35 | 40 | 10 | 414 | 35 | 40 | 10 | 55 | 35 | 20 | 35 |
| UV/IR 1S | 1092 | 35 | 60 | 10 | 883 | 35 | 55 | 25 | 0 | 0 | 0 | 0 |
| UV/IR 2 | 1067 | 35 | 60 | 10 | 1067 | 35 | 60 | 10 | 0 | 0 | 0 | 0 |
| UV/IR 3 | 553 | 25 | 55 | 15 | 395 | 25 | 50 | 15 | 0 | 0 | 0 | 0 |
| UV/IR 4 | 869 | 35 | 45 | 10 | 806 | 35 | 45 | 10 | 0 | 0 | 0 | 0 |
| UV/IR 5 | 2641 | 35 | 180 | 15 | 1721 | 35 | 180 | 10 | 0 | 0 | 0 | 0 |
| IR/IR 1 | 294 | 25 | 50 | 15 | 120 | 15 | 0 | 15 | 0 | 0 | 0 | 0 |
| IR/IR 2 | 808 | 35 | 45 | 10 | 709 | 35 | 45 | 10 | 0 | 0 | 0 | 0 |
| IR/IR 3 | 1008 | 35 | 55 | 30 | 322 | 25 | 55 | 10 | 0 | 0 | 0 | 0 |
| IR/IR 3 | 1137 | 35 | 55 | 30 | 544 | 35 | 55 | 10 | 0 | 0 | 0 | 0 |
| UV 1 | 1023 | 35 | 55 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| UV/UV/IR | 1702 | 35 | 80 | 30 | 1433 | 35 | 80 | 30 | 0 | 0 | 0 | 0 |

TABLE [illegible]. DETECTOR FOOTPRINT PARAMETERS, TEST 1A4.

| Type of detector | 15-Second response | | | | 5-Second response | | | | Blind spot | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Area, $ft^2$ | Rmx, ft | θmx, deg | Rθmx, ft | Area, $ft^2$ | Rmx, ft | θmx, deg | Rθmx, ft | Area, $ft^2$ | Bmx, ft | βmx, deg | Bβmx, ft |
| [illegible] IR 1 | [illegible] | [illegible] | [illegible] | 10 | 644 | 35 | 45 | 20 | 0 | 0 | 0 | 0 |
| [illegible] | [illegible] | [illegible] | 95 | 10 | 1040 | 35 | 95 | 10 | 234 | 15 | 0 | 15 |
| [illegible]/IR 2 | 1415 | 30 | 90 | 10 | 1415 | 35 | 90 | 10 | 0 | 0 | 0 | 0 |
| [illegible] | 1130 | [illegible] | 60 | 10 | 409 | 25 | 55 | 15 | 0 | 0 | 0 | 0 |
| [illegible] | [illegible] | [illegible] | [illegible] | 10 | 930 | 35 | 75 | 10 | 0 | 0 | 0 | 0 |
| [illegible] | [illegible] | [illegible] | [illegible] | 35 | [illegible] | 35 | 180 | 35 | 245 | 10 | 0 | 10 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 260 | 25 | 55 | 5 | 0 | 0 | 0 | 0 |
| [illegible] | [illegible] | [illegible] | [illegible] | 10 | 836 | 35 | 60 | 20 | 0 | 0 | 0 | 0 |
| [illegible] | [illegible] | 35 | 75 | 10 | 499 | 30 | 70 | 10 | [illegible] | 10 | 50 | [illegible] |
| [illegible] | [illegible] | 35 | 60 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| [illegible] | 3369 | 35 | 180 | 35 | 3064 | 35 | 180 | 35 | 0 | 0 | 0 | 0 |

TABLE 6. DETECTOR FOOTPRINT PARAMETERS, TEST 1B1.

| Type of detector | 15-Second response | | | | 5-Second response | | | | Blind spot | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Area, $ft^2$ | Rmx, ft | θmx, deg | Rθmx, ft | Area, $ft^2$ | Rmx, ft | θmx, deg | Rθmx, ft | Area, $ft^2$ | Bmx, ft | βmx, deg | Bβmx, ft |
| UV/IR 1 | 674 | 35 | 35 | 10 | 674 | 35 | 35 | 10 | 0 | 0 | 0 | 0 |
| UV/IR 1S | 785 | 35 | 65 | 10 | 391 | 35 | 65 | 10 | 102 | 10 | 35 | 10 |
| UV/IR 2 | 1082 | 35 | 65 | 10 | 1034 | 35 | 65 | 10 | 0 | 0 | 0 | 0 |
| UV/IR 3 | 504 | 25 | 45 | 25 | 439 | 25 | 45 | 20 | 0 | 0 | 0 | 0 |
| UV/IR 4 | 698 | 35 | 50 | 10 | 574 | 35 | 45 | 20 | 0 | 0 | 0 | 0 |
| UV/IR 5 | 2715 | 35 | 180 | 5 | 1717 | 30 | 180 | 5 | 0 | 0 | 0 | 0 |
| IR/IR 1 | 297 | 20 | 55 | 10 | 91 | 15 | 30 | 15 | 0 | 0 | 0 | 0 |
| IR/IR 2 | 724 | 35 | 50 | 10 | 593 | 35 | 50 | 10 | 0 | 0 | 0 | 0 |
| IR/IR 3 | 752 | 35 | 45 | 10 | 404 | 35 | 45 | 10 | 0 | 0 | 0 | 0 |
| UV 1 | 955 | 35 | 45 | 30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| UV/UV/IR | 2532 | 35 | 180 | 15 | 1812 | 35 | 180 | 15 | 0 | 0 | 0 | 0 |

TABLE 7. DETECTOR FOOTPRINT PARAMETERS, TEST 184.

| Type of detector | 15-Second response | | | | 5-Second response | | | | Blind spot | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Area, ft² | Rmx, ft | θmx, deg | Rθmx, ft | Area, ft² | Rmx, ft | θmx, deg | Rθmx, ft | Area, ft² | Rmx, ft | βmx, deg | Rβmx, ft |
| UV/IR 1 | 775 | [illegible] | 45 | 10 | 715 | 35 | 40 | 35 | 0 | 0 | 0 | 0 |
| UV/IR IS | 569 | [illegible] | 60 | 20 | 506 | 35 | 55 | 20 | 451 | 25 | 40 | 20 |
| UV/IR 2 | 1292 | 35 | 35 | 10 | 1392 | 35 | 85 | 10 | 0 | 0 | 0 | 0 |
| UV/IR | 1097 | [illegible] | 60 | 10 | 438 | 25 | 50 | 10 | 0 | 0 | 0 | 0 |
| UV/IR 4 | [illegible] | 35 | 65 | 10 | 718 | 35 | 65 | 10 | 0 | 0 | 0 | 0 |
| UV/IR 5 | 3611 | 35 | 120 | 35 | 2671 | 35 | 180 | 35 | 24[illegible] | 10 | 0 | 10 |
| IR [illegible] 1 | [illegible] | 35 | 85 | 10 | 765 | 30 | 75 | 15 | 0 | 0 | 0 | 0 |
| [illegible] 2 | 1280 | 35 | 80 | 10 | 1222 | 35 | 60 | 10 | 0 | 0 | 0 | 0 |
| [illegible] | 956 | 35 | 60 | 25 | 228 | 35 | 55 | 20 | 75 | 10 | 25 | 10 |
| [illegible] 1 | 1064 | [illegible] | 60 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| UV [illegible] | 3559 | 35 | 180 | 35 | 3064 | 35 | 180 | 35 | 0 | 0 | 0 | 0 |

Tables 8 and 9 show the maximum and average footprint areas for each type of detector as well as for all of the detectors. Separate categories which exclude the 360-degree FOV detectors from the total sum and the UV/IR detector groups are also shown. This was done because the footprint areas of the 360-degree FOV detectors (UV/IR 5 and UV/UV/IR) were so much larger than those of the other detectors that a very large bias in the data was created. The UV detector was not included in the 5-second response footprint area averages when it did not respond to the fire within 5 seconds. The tables show that, on the average, the UV/IR detectors tested have a much larger footprint than the IR/IR detectors tested. This difference is much larger for the 5-second footprints than for the 15-second footprints. These statements only apply to the average values. In each test, one or more of the IR/IR detectors performed as well as the average UV/IR detector. No comparison can be made for the UV and UV/UV/IR detectors, since only one of each was tested.

A smaller footprint does not necessarily mean that one detector is not as well suited for a particular application as one with a larger footprint. The fact that one detector has a smaller footprint than another can be compensated for by installing more detectors, and the decision of which type of detector is best for a particular application should be based on reliability, resistance to false alarm stimuli, initial total system cost, and recurring maintenance costs. Those detectors with very large footprints, UV/IR 5 and UV/UV/IR, have an advantage over those with smaller footprints, because fewer of these detectors would be required to cover the entire shelter, and this would presumably result in lower initial system costs.

Day-to-day changes in the environment of the shelter can explain some of the inconsistencies which show up in the data for the FOV test series. The test program began in August and continued for a little over a year. The seasonal difference between the high temperature for the day can be as much as 30 °F. During the winter it is not unusual for the day-to-day variation in the high temperature to be as much as 30 °F. On most days during the year, the difference between the high and low temperatures is usually 30 °F. Since the IR detectors are designed with components that may be temperature-sensitive, their response to a fire could be very different on a day-to-day or morning-to-afternoon basis.

TABLE 8. MAXIMUM FOOTPRINT AREAS (CLEAN SERIES).

| Type of detector | 15-Second response | | | | 5-Second response | | | |
|---|---|---|---|---|---|---|---|---|
| | 1A1 | 1A4 | 1B1 | 1B4 | 1A1 | 1A4 | 1B1 | 1B4 |
| All detectors | 2641 | 3859 | 2715 | 3859 | 1721 | 3064 | 1812 | 3064 |
| All detectors, non-360 FOV | 1702 | 1415 | 1082 | 1392 | 1433 | 1415 | 1034 | 1392 |
| UV/IR | 2641 | 3614 | 2715 | 3614 | 1721 | 2671 | 1717 | 2671 |
| UV/IR, non-360 FOV | 1092 | 1415 | 1082 | 1392 | 1067 | 1415 | 1034 | 1392 |
| IR/IR | 1137 | 1191 | 752 | 1287 | 709 | 836 | 593 | 1222 |
| UV | 1023 | 1073 | 955 | 1064 | 0 | 0 | 0 | 0 |
| UV/UV/IR | 1702 | 3859 | 2532 | 3859 | 1433 | 3064 | 1812 | 3064 |

TABLE 9. AVERAGE FOOTPRINT AREA (CLEAN SERIES).

| Type of detector | 15-Second response | | | | 5-Second response | | | |
|---|---|---|---|---|---|---|---|---|
| | 1A1 | 1A4 | 1B1 | 1B4 | 1A1 | 1A4 | 1B1 | 1B4 |
| All detectors | 1076 | 1619 | 1055 | 1520 | 765 | 1167 | 773 | 1172 |
| All detectors, non-360 FOV | 933 | 1149 | 719 | 1034 | 669 | 742 | 525 | 748 |
| UV/IR | 1156 | [illegible] | 1076 | 1399 | 891 | 1168 | 905 | 1073 |
| UV/IR, non-360 FOV | 959 | 1193 | [illegible] | [illegible] | 713 | 863 | 622 | 754 |
| IR/IR | 812 | 1100 | 593 | 1175 | 424 | 532 | 363 | 738 |
| UV | 1023 | [illegible] | 955 | [illegible] | 0 | 0 | 0 | 0 |
| UV/UV/IR | 1702 | [illegible] | 2532 | 3859 | 1433 | 3064 | 1812 | 3064 |

During the winter, the test area was also subject to temperature inversions which trapped the smoke from the fires inside the shelter and drastically reduced visibility. Wind was also a factor in the testing. A plywood shield, 10-feet high by 12-feet long, was erected to protect the test fires from the wind, but even a slight breeze would change the height of the fire and cause it to lean over to one side. The shield was located 7 feet upwind from the fire pan. This explains the one-sideness of some of the footprint in Figure 9. A breeze could also cause large changes in the footprint areas, especially during testing at the larger radii. No testing was conducted during high wind conditions. The timetable for this program did not allow a delay in testing in order to conduct testing under similar environmental conditions for all of the detectors. However, the test program was conducted in such a way that all detectors were subjected to the current test before a different test series was begun.

5. Dirty Test Series

The dirty test series was conducted to determine the effect of long-term exposure to the HAS environment on the performance of the detector. The major factor causing degradation of detector performance was the presence of contaminants on the lens of the detector. This effect was measured by contaminating a calcium fluoride substrate and measuring the change in detector performance caused by decreased visibility as the detector looked through the substrate. Calcium fluoride was chosen because it has very low absorption in the UV and IR bandwidths. The performance of the detectors was measured using a clean substrate. The performance tests were the same as those conducted during the clean test series. The substrate was then contaminated with smoke from burning JP-4. The smoke was used to simulate contamination that may occur from the exhaust of engines running while aircraft are in the HAS. The performance tests were then repeated, using the dirty substrate. The test numbers and their descriptions are given below.

| Test | Description |
|---|---|
| 2A1 | Detector looking through a clean $CaF_2$ substrate at a 1 $ft^2$ pan fire |
| 2A4 | Detector looking through a clean $CaF_2$ substrate at a 4 $ft^2$ pan fire |
| 2B1 | Detector looking through a dirty $CaF_2$ substrate at a 1 $ft^2$ pan fire |
| 2B4 | Detector looking through a dirty $CaF_2$ substrate at a 4 $ft^2$ pan fire |

Blinders were installed on detector [illegible] (IR [illegible]) during the dirty substrate tests. This was to prevent the detector from being triggered by reflections of the flame off the dirty substrate when the detector was at an obtuse angle relative to the fire. The blinder was used to cover the area between the detector body and the edge of the substrate. Therefore, the only light that the detector was allowed to see had passed through the substrate.

The results of the tests conducted in the dirty test series are shown in Tables 10 through 1[illegible]. The area of the 15-second response footprints [illegible] the clean substrate ranged from 29[illegible] to [illegible] ft². The area of the footprints [illegible] the dirty substrate ranged from 4[illegible] to 2250 ft². The area of the [illegible] response footprints ranged from 0 to [illegible] ft² for the clean substrate and from 0 to 1110 ft² for the dirty substrate. The effects of the substrate and [illegible] on the footprint areas of the detectors were variable, with [illegible] detectors showing performance improvements, some showing degradation, and others showing no change. Table 14 shows the average footprint areas for the different types of detectors. Tests 1[illegible] and 104 are shown to allow direct comparison of the $CaF_2$ substrate. Tables 15 and 16 summarize the data in Table 14 and show the effect of the $CaF_2$ substrate on the average footprint [illegible] different types of detectors. There was [illegible] on the footprint area for the UV/IR detector. The effect of the $CaF_2$ substrate on the footprint area of the IR/IR detectors for the 15-second [illegible] was [illegible], but the areas were larger with the substrate than without it for the [illegible] response footprints. Table 1[illegible] [illegible] types of performance [illegible] $CaF_2$ substrates. The data [illegible] for [illegible] the substrates [illegible]

TABLE 10. DETECTOR FOOTPRINT PARAMETERS, TEST 2A1.

| Type of detector | 15-Second response | | | | 5-Second response | | | | Blind spot | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Area, $ft^2$ | Rmx, ft | θmx, deg | Rθmx, ft | Area, $ft^2$ | Rmx, ft | θmx, deg | Rθmx, ft | Area, $ft^2$ | Bmx, ft | βmx, deg | Bβmx, ft |
| UV/IR 1 | 750 | 35 | 35 | 35 | 585 | 35 | 35 | 35 | 0 | 0 | 0 | 0 |
| UV/IR 1S | 841 | 35 | 40 | 30 | 841 | 35 | 40 | 30 | 0 | 0 | 0 | 0 |
| UV/IR 2 | 1104 | 35 | 60 | 10 | 1104 | 35 | 60 | 10 | 0 | 0 | 0 | 0 |
| UV/IR 3 | 552 | 25 | 50 | 20 | 504 | 25 | 50 | 20 | 0 | 0 | 0 | 0 |
| UV/IR 4 | 1059 | 35 | 90 | 10 | 667 | 35 | 90 | 10 | 0 | 0 | 0 | 0 |
| UV/IR 5 | 2651 | 35 | 180 | 15 | 1850 | 35 | 180 | 10 | 0 | 0 | 0 | 0 |
| IR/IR 1 | 295 | 25 | 50 | 10 | 124 | 15 | 0 | 15 | 0 | 0 | 0 | 0 |
| IR/IR 2 | 869 | 35 | 45 | 25 | 869 | 35 | 45 | 25 | 0 | 0 | 0 | 0 |
| IR/IR 3 | 1066 | 35 | 55 | 10 | 624 | 35 | 55 | 10 | 0 | 0 | 0 | 0 |
| UV 1 | 1048 | 35 | 55 | 20 | 354 | 35 | 0 | 35 | 0 | 0 | 0 | 0 |

Note: The UV/UV/IR detector was not tested because it did not fit behind the $CaF_2$ substrate.

TABLE [illegible]. DETECTOR FOOTPRINT PARAMETERS, TEST 2A4.

| Type of detector | 15-second response | | | | 5-Second response | | | | Blind spot | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Area, ft² | Rmx, ft | θmx, deg | Rθmx, ft | Area, ft² | Rmx, ft | θmx, deg | Rθmx, ft | Area, ft² | Bmx, ft | βmx, deg | Bβmx, ft |
| UV/IR 1 | [illegible] | 35 | 45 | 10 | 713 | 35 | 55 | 10 | 0 | 0 | 0 | 0 |
| UV/IR 1S | 1017 | 35 | 40 | 25 | 877 | 35 | 50 | 25 | 0 | 0 | 0 | 0 |
| UV/IR 2 | 1418 | 25 | 90 | 10 | 1418 | 35 | 90 | 10 | 0 | 0 | 0 | 0 |
| UV/IR 3 | 1181 | 35 | 60 | 10 | 366 | 25 | 0 | 25 | 0 | 0 | 0 | 0 |
| UV/IR 4 | 1203 | 35 | [illegible] | 10 | 1052 | 35 | 75 | 10 | 0 | 0 | 0 | 0 |
| UV/IR 5 | 3613 | 35 | 180 | 35 | 2670 | 35 | 180 | 35 | 245 | 10 | 0 | 10 |
| IR/IR 1 | 1084 | 35 | 55 | 10 | 490 | 30 | 55 | 10 | 0 | 0 | 0 | 0 |
| IR/IR 2 | 1150 | 35 | 85 | 10 | 1085 | 35 | 85 | 10 | 0 | 0 | 0 | 0 |
| IR/IR 3 | 1244 | 35 | 60 | 20 | 340 | 35 | 60 | 20 | 0 | 0 | 0 | 0 |
| [illegible] | 1073 | 35 | 60 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Note: [illegible] UV/UV/IR detector was not tested because it did not fit behind the $CaF_2$ substrate.

TABLE 12. DETECTOR FOOTPRINT PARAMETERS, TEST 2B1.

| Type of detector | 15-Second response | | | | 5-Second response | | | | Blind spot | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Area, $ft^2$ | Rmx, ft | θmx, deg | Rθmx, ft | Area, $ft^2$ | Rmx, ft | θmx, deg | Rθmx, ft | Area, $ft^2$ | Bmx, ft | βmx, deg | Bβmx, ft |
| UV/IR 1 | 989 | 35 | 70 | 10 | 861 | 35 | 45 | 15 | 0 | 0 | 0 | 0 |
| UV/IR 1S | 989 | 35 | 70 | 10 | 861 | 35 | 45 | 15 | 0 | 0 | 0 | 0 |
| UV/IR 2 | 1053 | 35 | 55 | 10 | 1053 | 35 | 55 | 10 | 0 | 0 | 0 | 0 |
| UV/IR 3 | 477 | 25 | 55 | 15 | 160 | 25 | 55 | 10 | 0 | 0 | 0 | 0 |
| UV/IR 4 | 1070 | 35 | 60 | 10 | 934 | 35 | 60 | 10 | 0 | 0 | 0 | 0 |
| UV/IR 5[a] | 1570 | 35 | 85 | 10 | 1115 | 35 | 75 | 20 | 0 | 0 | 0 | 0 |
| IR/IR 1 | 447 | 30 | 60 | 10 | 78 | 10 | 0 | 10 | 0 | 0 | 0 | 0 |
| IR/IR 2 | 833 | 35 | 50 | 10 | 753 | 35 | 50 | 10 | 0 | 0 | 0 | 0 |
| IR/IR 3 | 1051 | 35 | 50 | 20 | 118 | 30 | 0 | 30 | 0 | 0 | 0 | 0 |
| UV 1 | 583 | 35 | 35 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Note: The UV/UV/IR detector was not tested because it did not fit behind the $CaF_2$ substrate.

[a]Blinders were installed on detector to prevent reflection.

TABLE 13. DETECTOR FOOTPRINT PARAMETERS, TEST 2B4.

| Type of detector | 15-Second response | | | | 5-Second response | | | | Blind spot | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Area, ft$^2$ | Rmx, ft | θmx, deg | Rθmx, ft | Area, ft$^2$ | Rmx, ft | θmx, deg | Rθmx, ft | Area, ft$^2$ | Rmx, ft | βmx, deg | Rβmx, ft |
| UV/IR 1 | 997 | 35 | 85 | 10 | 694 | 35 | 55 | 15 | 187 | 15 | 0 | 15 |
| UV/IR 1S | 997 | 35 | 85 | 10 | 565 | 35 | 55 | 15 | 187 | 15 | 0 | 15 |
| UV/IR 2 | 1410 | 35 | 80 | 20 | 1410 | 35 | 80 | 20 | 0 | 0 | 0 | 0 |
| UV/IR 3 | 1127 | 35 | 70 | 10 | 140 | 10 | 65 | 10 | 0 | 0 | 0 | 0 |
| UV/IR 4 | 1272 | 35 | 80 | 10 | 1098 | 35 | 80 | 10 | 0 | 0 | 0 | 0 |
| UV/IR 5 | 2256 | 35 | 180 | 10 | 1064 | 35 | 110 | 30 | 245 | 10 | 0 | 10 |
| IR/IR 1 | 1265 | 35 | 70 | 15 | 460 | 25 | 70 | 10 | 0 | 0 | 0 | 0 |
| IR/IR 2 | 1025 | 35 | 70 | 10 | 1025 | 35 | 70 | 10 | 0 | 0 | 0 | 0 |
| IR/IR 3 | 823 | 35 | 50 | 15 | 299 | 35 | 45 | 20 | 122 | 15 | 35 | 10 |
| UV 1 | 562 | 25 | 50 | 25 | 270 | 25 | 0 | 25 | 0 | 0 | 0 | 0 |

Note: The UV/UV/IR detector was not tested because it did not fit behind the $CaF_2$ substrate.

TABLE 14. AVERAGE FOOTPRINT AREAS ($FT^2$), CLEAN AND DIRTY.

| Type of detector | 15-Second response | | | | | | 5-Second response | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1A1 | 2A1 | 2B1 | 1A4 | 2A4 | 2B4 | 1A1 | 2A1 | 2B1 | 1A4 | 2A4 | 2B4 |
| All detectors | 1076 | 1024 | 906 | 1389 | 1619 | 1174 | 765 | 752 | 659 | 1167 | 1001 | 703 |
| All detectors, non-360 FOV | 933 | 843 | 906 | 1142 | 1149 | 1054 | 669 | 630 | 659 | 742 | 793 | 662 |
| UV/IR | 1156 | 1160 | 1025 | 1557 | 1597 | 1343 | 881 | 925 | 831 | 1168 | 1183 | 812 |
| UV/IR, non-360 FOV | 859 | 861 | 1025 | 1146 | 1193 | 1161 | 713 | 740 | 831 | 868 | 885 | 781 |
| IR/IR | 812 | 743 | 777 | 1159 | 1100 | 1038 | 424 | 539 | 316 | 532 | 638 | 595 |
| UV | 1023 | 1048 | 583 | 1073 | 1073 | 568 | 0 | 354 | 0 | 0 | 0 | 270 |
| UV/UV/IR | 1702 | NA | NA | NA | 3859 | NA | 1433 | NA | NA | 3064 | NA | NA |

Note: NA indicates no data were available.

TABLE 15. EFFECT OF CLEAN $CaF_2$ SUBSTRATE ON AVERAGE FOOTPRINT AREA (15-SECOND RESPONSE).

| Average footprint area, $ft^2$ | All detectors | All detectors, non-360 | UV/IR | UV/IR non-360 | IR/IR | UV | UV/UV/IR |
|---|---|---|---|---|---|---|---|
| 1 | None | NS>sub | None | None | NS>sub | None | NA |
| 4 | NS<sub | None | None | None | None | None | NA |

Notes: Sub indicates substrate footprint area.

NS indicates footprint area without substrate.

NA indicates no data were available.

TABLE 16. EFFECT OF CLEAN $CaF_2$ SUBSTRATE ON AVERAGE FOOTPRINT AREA (5-SECOND RESPONSE).

| Average footprint area, $ft^2$ | All detectors | All detectors, non-360 | UV/IR | UV/IR non-360 | IR/IR | UV | UV/UV/IR |
|---|---|---|---|---|---|---|---|
| 1 | None | NS>sub | None | None | Sub>ns | NA | NA |
| 4 | NS>sub | None | None | None | Sub>ns | NA | NA |

Notes: Sub indicates substrate footprint area.

NS indicates footprint area without substrate.

NA indicates no data were available.

TABLE 17. NUMBER OF DETECTORS AFFECTED BY CLEAN $CaF_2$ SUBSTRATE.

| Type of detector | Average footprint area, $ft^2$ | 15-Second response | | | 5-Second response | | |
|---|---|---|---|---|---|---|---|
| | | Subst> | No subst> | No effect | Subst> | No subst> | No effect |
| UV/IR | 1 | 1 | 1 | 4 | 4 | 1 | 1 |
| UV/IR | 4 | 0 | 1 | 5 | 2 | 2 | 2 |
| IR/IR | 1 | 1 | 0 | 2 | 2 | 0 | 1 |
| IR/IR | 4 | 2 | 1 | 0 | 1 | 2 | 0 |

Notes: UV/IR detectors 1-6 (total of 6) and IR/IR detectors 1-3 were tested.

Subst> indicates that footprint area with substrate was larger than footprint area without substrate.

No subst> indicates that footprint area without substrate was larger than footprint area with substrate.

No effect indicates that footprint areas with and without substrate were within 5 percent of each other.

TABLE 15. NUMBER OF DETECTORS AFFECTED BY DIRTY SUBSTRATE.

| Type of detector | Average footprint area, $ft^2$ | 15-Second response | | | 5-Second response | | |
|---|---|---|---|---|---|---|---|
| | | Subst> | No subst> | No effect | Subst> | No subst> | No effect |
| UV/IR | 1 | 1 | 1 | 4 | 4 | 1 | 1 |
| UV/IR | 4 | 0 | 1 | 5 | 2 | 2 | 2 |
| IR/IR | 1 | 1 | 0 | 2 | 2 | 0 | 1 |
| IR/IR | 4 | 2 | 1 | 0 | 1 | 2 | 0 |

Notes: UV/IR detectors 1-5 (total of 6) and IR/IR detectors 1-3 were tested.

Subst> indicates that footprint area with dirty substrate was larger than footprint area with clean substrate.

No subst> indicates that footprint area with clean substrate was larger than footprint area with dirty substrate.

No effect indicates that footprint areas with clean and dirty substrates were within five percent of each other.

detectors of each type having a specific type of footprint area change for each of the tests performed. The performance effect on the UV/IR detectors had no consistent trend. The effect was also variable on the IR/IR detectors, although there was a tendency for the dirty substrate to decrease the footprint areas, especially for the 4 $ft^2$ fires. There was a large performance degradation for the UV detector with dirty optics. Tables 19 and 20 summarize the data from Table 14 showing the effect of the dirty substrate on average footprint areas for the different types of detectors. While the effect is somewhat variable on the 15-second response footprints, almost all detector types performed much better with clean optics when the 5-second response criterion was used. This effect was more pronounced on the UV/IR detectors than on the IR/IR detectors.

Examination of the results showing the effect of substrate contamination on footprint areas of the individual UV/IR and IR/IR detectors seems to contradict the general maxim that UV detectors are more susceptible to contamination than IR detectors. However, examining the average footprints shows this effect to be true, although UV/IR detectors were not as sensitive as the UV detector. The results show that all detector types need a program of detector front lens cleaning to maintain optimum performance, and that single-channel UV detectors will require more frequent cleaning than a UV/IR detector.

TABLE 19. EFFECT OF DIRTY SUBSTRATE ON AVERAGE FOOTPRINT AREA ([illegible]-SECOND RESPONSE).

| Average footprint area, ft² | All detectors | All detectors, non-360 | UV/IR | UV/IR non-360 | IR/IR | UV | UV/UV/IR |
|---|---|---|---|---|---|---|---|
| 1 | CL>DT | DT>CL | CL>DT | [illegible] | None | CL>>DT | NA |
| 4 | [illegible] | DT>CL | None | None | None | DT>>CL | NA |

Notes: CL indicates clear substrate footprint area.
DT indicates dirty substrate footprint area.
NA indicates data were not available.

TABLE 20. EFFECT OF DIRTY SUBSTRATE ON AVERAGE FOOTPRINT AREA (5-SECOND RESPONSE).

| Average footprint area, ft² | All detectors | All detectors, non-360 | UV/IR | UV/IR non-360 | IR/IR | UV | UV/UV/IR |
|---|---|---|---|---|---|---|---|
| 1 | CL>DT | None | CL>DT | DT>CL | CL>>DT | NA | NA |
| 4 | CL>>DT | CL>DT | CL>>DT | CL>DT | CL>DT | NA | NA |

Notes: CL indicates clear substrate footprint area.
DT indicates dirty substrate footprint area.
NA indicates data were not available.

In a related test series, optical substrates were suspended in operational HASs in England and Germany. Before the substrates were hung, measurements were made of the absorption spectra and optical quality of the sapphire and quartz substrates. The substrates were retrieved after 120 days and the measurements were repeated. The records from the pre- and posttest measurements were then compared. This showed the amount of particulate contamination that would be expected during operation. These tests are discussed in detail in Section III.

The data from the dirty test series seem to conflict with those in the ambient environment section of the report. The data in the ambient environment section of the report show that the JP-4 soot found in the HAS environment has its greatest effect on UV in the 200-245 nm region, the same region where most UV detectors work. However, the data from the dirty test series show that there is still a signal strong enough to permit the UV channels of the detectors to work. The performance will remain fairly stable until the attenuation reaches a level high enough to cause the UV performance to drop dramatically.

6. Elevated Test Series

In the HAS application the OFD will most likely be mounted approximately 10 feet above the floor. The effect of the slight angle will be to shorten the flame front, thereby reducing the radiation propagating frontal area. These tests were conducted to determine if this decreased visibility affected OFD performance. During this test series, the detectors were mounted on a tripod 10 feet above the ground and pointed directly across the shelter at the point where the floor meets the wall. The field of view was mapped using the tests below.

| Test | Description |
|---|---|
| 3A1 | Detector in manufacturer's recommended installation position with a 1 $ft^2$ pan fire |
| 3A[illegible] | Same as 3A1 except with 4 $ft^2$ pan fire |

Table 21 shows the performance parameters for the detectors looking at the 1 $ft^2$ fire. The 15-second response footprint areas ranged from 386 to 2559 $ft^2$. The 5-second response footprints ranged from 0 to 1694 $ft^2$. All of the detectors saw the fire at the maximum range within 15 seconds except detector IR/IR 1, which could not see fires more than 25 feet from the detector. Three detectors, UV 1, IR/IR 1 and IR/IR 3, could not see fires at the maximum range within 5 seconds.

Table 22 shows the performance parameters for the elevated detectors looking at the 4 $ft^2$ fire. The 15-second response footprints range from 834 to 3614 $ft^2$, while the 5-second footprints range from 0 to 3064 $ft^2$. All of the detectors saw the fire at the maximum range within 15 seconds, but detectors UV 1 and IR/IR 1 could not see fires at the maximum range within 5 seconds. Detectors UV/IR 15, UV/IR 5, IR/IR 3 and UV/UV/IR had blind spots. All of the blind spots were at points on radii close to the detector.

Table 23 shows the average footprint areas for the plane and elevated test series. It allows a direct comparison of the footprint areas for the different types of detectors. On the average the detectors had larger footprints in the elevated position than in the lower mounting position. This is shown in Tables 24 through 26, which summarize the results in Tables 21 through 23. Tables 24 and 25 show that the average footprint areas are larger in the elevated position or are unchanged from the lower plane position for all but four of the categories (28 total). Table 26 shows that almost all of the detectors performed in the elevated position as well as or better than in the lower plane position.

Elevating the detectors generally [illegible] their performance. [illegible] level [illegible] evaluators [illegible] what the elevated test series [illegible] still be able to determine [illegible] area a detector could [illegible] elevated position.

TABLE 21. FOOTPRINT PARAMETERS FOR ELEVATED TEST SERIES, TEST 3A1.

| Type of detector | 15-Second response | | | | 5-Second response | | | | Blind spot | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Area, $ft^2$ | Rmx, ft | θmx, deg | Rθmx, ft | Area, $ft^2$ | Rmx, ft | θmx, deg | Rθmx, ft | Area, $ft^2$ | βmx, ft | βmx, deg | Rβmx, ft |
| UV/IR 1 | 722 | 35 | 40 | 10 | 722 | 35 | 40 | 10 | 0 | 0 | 0 | 0 |
| UV/IR 1S | 1075 | 35 | 55 | 25 | 995 | 35 | 55 | 25 | 0 | 0 | 0 | 0 |
| UV/IR 2 | 1175 | 35 | 85 | 10 | 1175 | 35 | 85 | 10 | 0 | 0 | 0 | 0 |
| UV/IR 3 | 1121 | 35 | 65 | 15 | 154 | 35 | 65 | 15 | 0 | 0 | 0 | 0 |
| UV/IR 4 | 1048 | 35 | 75 | 10 | 1048 | 35 | 75 | 10 | 0 | 0 | 0 | 0 |
| UV/IR 5 | 2559 | 35 | 180 | 10 | 1694 | 35 | 180 | 10 | 0 | 0 | 0 | 0 |
| IR/IR 1 | 386 | 25 | 50 | 15 | 172 | 20 | 0 | 20 | 0 | 0 | 0 | 0 |
| IR/IR 2 | 909 | 35 | 45 | 20 | 883 | 35 | 45 | 20 | 0 | 0 | 0 | 0 |
| IR/IR 3 | 1136 | 35 | 80 | 10 | 442 | 30 | 75 | 10 | 0 | 0 | 0 | 0 |
| UV 1 | 1105 | 35 | 55 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| UV/UV/IR | 1702 | 35 | 80 | 30 | 1217 | 35 | 80 | 25 | 0 | 0 | 0 | 0 |

TABLE 22. FOOTPRINT PARAMETERS FOR ELEVATED TEST SERIES, TEST 3A4.

| Type of detector | 10-Second response | | | | 5-Second response | | | | Blind spot | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Area, $ft^2$ | Rmx, ft | θmx, deg | Rθmx, ft-deg | Area, $ft^2$ | Rmx, ft | θmx, deg | Rθmx, ft-deg | Area, $ft^2$ | Rmx, ft | θmx, deg | Rθmx, ft-deg |
| UV/IR 1 | 930 | 35 | 55 | 10 | 894 | 35 | 55 | 10 | 0 | 0 | 0 | 0 |
| UV/IR 1S | 1257 | 35 | 90 | 10 | 1083 | 35 | 90 | 10 | 221 | 15 | 0 | 15 |
| UV/IR 2 | 1409 | 35 | 90 | 10 | 1409 | 35 | 90 | 10 | 0 | 0 | 0 | 0 |
| UV/IR 3 | 1286 | 35 | 65 | 10 | 66 | 35 | 0 | 35 | 0 | 0 | 0 | 0 |
| UV/IR 4 | 1319 | 35 | 110 | 10 | 1434 | 35 | 110 | 10 | 0 | 0 | 0 | 0 |
| UV/IR 5 | 3613 | 35 | 180 | 35 | 2671 | 35 | 180 | 35 | 245 | 10 | 0 | 10 |
| IR/IR 1 | 1080 | 35 | 55 | 10 | 536 | 35 | 55 | 10 | 0 | 0 | 0 | 0 |
| IR/IR 2 | 1152 | 35 | 85 | 10 | 1152 | 35 | 85 | 10 | 0 | 0 | 0 | 0 |
| IR/IR 3 | 834 | 35 | 70 | 10 | 203 | 35 | 40 | 25 | 184 | 10 | 65 | 10 |
| UV 1 | 1123 | 35 | 60 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| UV/UV/IR | 3614 | 35 | 180 | 35 | 3064 | 35 | 180 | 35 | 245 | 10 | 0 | 10 |

TABLE 23. AVERAGE FOOTPRINT AREAS ($FT^2$) FOR PLANE AND ELEVATED DETECTORS.

| Type of detector | 15-Second response | | | | 5-Second response | | | |
|---|---|---|---|---|---|---|---|---|
| | 1A1 | 3A1 | 1A4 | 3A4 | 1A1 | 3A1 | 1A4 | 3A4 |
| All detectors | 1076 | 1176 | 1619 | 1621 | 765 | 850 | 1167 | 1251 |
| All detectors, non-360 FOV | 933 | 1038 | 1149 | 1178 | 669 | 756 | 742 | 847 |
| UV/IR | 1156 | 1283 | 1597 | 1671 | 881 | 965 | 1168 | 1260 |
| UV/IR, non-360 FOV | 859 | 1028 | 1193 | 1282 | 713 | 819 | 868 | 977 |
| IR/IR | 812 | 810 | 1100 | 1022 | 424 | 499 | 532 | 630 |
| UV | 1023 | 1105 | 1073 | 1123 | 0 | 0 | 0 | 0 |
| UV/UV/IR | 1702 | 1702 | 3859 | 3614 | 1433 | 1217 | 3064 | 3064 |

TABLE 24. EFFECT OF ELEVATION ON AVERAGE FOOTPRINT AREA (15-SECOND RESPONSE).

| Fire size, $ft^2$ | All detectors | All detectors, non-360 | UV/IR | UV/IR non-360 | IR/IR | UV | UV/UV/IR |
|---|---|---|---|---|---|---|---|
| 1 | EL>PL | EL>PL | EL>PL | EL>PL | None | EL>PL | None |
| 4 | None | None | EL>PL | EL>PL | PL>EL | None | PL>EL |

Notes: EL indicates elevated footprint area.
PL indicates footprint area in fire plane.
None indicates footprint areas within 5 percent of each other.

TABLE 25. EFFECT OF ELEVATION ON AVERAGE FOOTPRINT AREA (5-SECOND RESPONSE).

| Fire size, $ft^2$ | All detectors | All detectors, non-360 | UV/IR | UV/IR, non-360 | IR/IR | UV | UV/UV/IR |
|---|---|---|---|---|---|---|---|
| 1 | EL>PL | EL>PL | EL>PL | EL>PL | EL>PL | NA | PL>EL |
| 4 | EL>PL | EL>PL | PL>EL | PL>EL | PL>EL | NA | None |

Notes: EL indicates elevated footprint area.
PL indicates footprint area in fire plane.
None indicates footprint areas within 5 percent of each other.

TABLE 26. TABULATION OF DETECTOR FOOTPRINT AREA CHANGES CAUSED BY ELEVATION.

| Type of detector | Fire size, $ft^2$ | 15-Second response | | | 5-Second response | | |
|---|---|---|---|---|---|---|---|
| | | Elev> | Plane> | No effect | Elev> | Plane> | No effect |
| UV/IR | 1 | 1 | 1 | 4 | 4 | 1 | 1 |
| UV/IR | 4 | 0 | 1 | 5 | 2 | 2 | 2 |
| IR/IR | 1 | 1 | 0 | 2 | 2 | 0 | 1 |
| IR/IR | 4 | 2 | 1 | 0 | 1 | 2 | 0 |

Notes: Elev> indicates elevated footprint area was larger than fire plane footprint area.

Plane> indicates fire plane footprint area was larger than elevated footprint area.

No effect indicates fire plane footprint and elevated footprint areas were within 5 percent of each other.

7. Hot/Cold Test Series

The hot/cold test series was conducted to simulate the temperature extremes that would be seen by the detector in an operational environment and to determine their effect on detector performance. IR OFDs generally use thermopiles or pyroelectric sensors as detectors. These detectors are inherently susceptible to changes in ambient temperature. The manufacturers of these OFDs build in circuitry in an attempt to overcome this dependence. These tests were designed to determine how well the various detectors handle this problem.

During this test series, the FOV was mapped using the procedures employed in the clean test series. Both test series were conducted using 1 $ft^2$ fire. During the cold test the detector was mounted in a modified refrigerator-freezer maintained at 0 °F. This test was labeled 5A. The hot tests were conducted with the detectors mounted in an oven maintained at 110 °F. This test is labeled 5B. Tables 27 and 28 show the performance parameters for the cold and hot tests for each detector.

TABLE 27. DETECTOR PERFORMANCE PARAMETERS, TEST 5A.

| Type of detector | 15-Second response | | | | 5-Second response | | | | Blind spot | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Area, $ft^2$ | $R_{mx}$, ft | $\theta_{mx}$, deg | $R_{\theta mx}$, ft | Area, $ft^2$ | $R_{mx}$, ft | $\theta_{mx}$, deg | $R_{\theta mx}$, ft | Area, $ft^2$ | $B_{mx}$, ft | $\beta_{mx}$, deg | $B_{\beta mx}$, ft |
| UV/IR 1 | 835 | 35 | 45 | 10 | 782 | 35 | 45 | 10 | 0 | 0 | 0 | 0 |
| UV/IR 1S | 1077 | 35 | 55 | 20 | 1023 | 35 | 55 | 20 | 0 | 0 | 0 | 0 |
| UV/IR 2 | 1077 | 35 | 55 | 15 | 1077 | 35 | 55 | 15 | 0 | 0 | 0 | 0 |
| UV/IR 3 | 528 | 25 | 50 | 15 | 307 | 25 | 50 | 10 | 0 | 0 | 0 | 0 |
| UV/IR 4 | 897 | 35 | 45 | 15 | 835 | 35 | 45 | 15 | 0 | 0 | 0 | 0 |
| IR/IR 1 | 316 | 25 | 50 | 10 | 127 | 15 | 0 | 15 | 0 | 0 | 0 | 0 |
| IR/IR 2 | 827 | 35 | 45 | 10 | 827 | 35 | 45 | 10 | 0 | 0 | 0 | 0 |
| IR/IR 3 | 1115 | 35 | 55 | 30 | 330 | 25 | 0 | 25 | 0 | 0 | 0 | 0 |

Note: Detectors UV/IR5, UV 1, and UV/UV/IR were not included because they were not sealed against moisture condensation.

TABLE 28. DETECTOR PERFORMANCE PARAMETERS, TEST 5B.

| Type of detector | 15-Second response | | | | 5-Second response | | | | Blind spot | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Area, $ft^2$ | Rmx, ft | θmx, deg | Rθmx, ft | Area, $ft^2$ | Rmx, ft | θmx, deg | Rθmx, ft | Area, $ft^2$ | Bmx, ft | βmx, deg | Bβmx, ft |
| UV/IR 1 | 743 | 35 | 45 | 15 | 714 | 35 | 45 | 15 | 116 | 10 | 40 | 10 |
| UV/IR 1S | 1299 | 35 | 85 | 10 | 962 | 35 | 85 | 10 | 116 | 10 | 0 | 10 |
| UV/IR 2 | 1416 | 35 | 85 | 10 | 1416 | 35 | 85 | 10 | 0 | 0 | 0 | 0 |
| UV/IR 3 | 1044 | 35 | 50 | 20 | 544 | 30 | 50 | 15 | 0 | 0 | 0 | 0 |
| UV/IR 4 | 1165 | 35 | 70 | 10 | 784 | 35 | 70 | 10 | 0 | 0 | 0 | 0 |
| UV/IR 5 | 1484 | 35 | 85 | 10 | 343 | 20 | 0 | 20 | 0 | 0 | 0 | 0 |
| IR/IR 1 | 1016 | 35 | 45 | 35 | 627 | 25 | 45 | 25 | 0 | 0 | 0 | 0 |
| IR/IR 2 | 1117 | 35 | 70 | 10 | 939 | 35 | 70 | 10 | 0 | 0 | 0 | 0 |
| IR/IR 3 | 766 | 30 | 55 | 10 | 209 | 20 | 0 | 20 | 0 | 0 | 0 | 0 |
| UV 1 | 296 | 25 | 30 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Note: Detector UV/UV/IR was not tested because it was not able to fit into the oven.

Table 29 shows the average footprint areas for each type of detector under cold, ambient and hot conditions. Test 1A1 was used as the ambient conditions test. All of the 15-second response footprint areas were larger in hot conditions than they were in cold conditions. The UV/IR detectors had essentially the same 5-second response footprint areas under hot and cold conditions. The IR/IR detectors had larger hot footprint areas than cold. The ambient footprint areas did not tend to be between those of the hot and cold tests. Some of the bias in the data can be attributed to the fact that the 360-degree FOV detectors are included in some of the ambient averages, but are not included in the cold or hot test averages because they were not sealed against moisture or would not fit in the oven. The cases in which the ambient footprint areas are not between the cold and hot areas and which cannot be accounted for by the data bias may have been caused by the day-to-day changes in the environment of the shelter, which may have caused changes in detector performance.

TABLE 29. AVERAGE FOOTPRINT AREAS ($FT^2$) FOR HOT, COLD, AND AMBIENT CONDITIONS.

| Type of detector | 15-Second response | | | 5-Second response | | |
|---|---|---|---|---|---|---|
| | Cold | Amb | Hot | Cold | Amb | Hot |
| All detectors | 834 | 1076 | 1035 | 664 | 765 | 725 |
| All detectors, non-360 FOV | 834 | 933 | 1035 | 664 | 669 | 726 |
| UV/IR | 883 | 1156 | 1192 | 805 | 881 | 794 |
| UV/IR, non-360 FOV | 883 | 859 | 1192 | 805 | 713 | 794 |
| IR/IR | 753 | 812 | 966 | 428 | 424 | 592 |
| UV | NA | 1023 | 296 | NA | 0 | 0 |
| UV/UV/IR | NA | 1702 | NA | NA | 1433 | NA |

Note: NA indicates no data were available.

8. False-Alarm Test Series

The false-alarm test series was conducted to determine the response of the detectors to light stimuli from sources other than fire. The light sources were chosen based upon the possibility that the detectors could see light and initiate a false dump of extinguishing agent from these sources during their lifetime. The tests were conducted in the GAS with all of the detectors mounted in the same plane on top of a metal horse 41 inches above the floor. The tests were numbered from 4.A1 through 4.ZZ and are described below.

4.A1 Vehicle Head Lamps (Day): Two single-beam (6014) head lamps operating at 12 V DC were mounted on the front of a truck. The head lamps directly faced the detectors, and were spaced 45 inches apart from center to center and 27 inches above the ground. In the first test the detectors faced west with the head lamps 35 feet away. Head lamps were flashed on and off slowly (every 3 seconds), then rapidly (approximately every .30 second). Next, the head lamps were switched from high to low in rapid succession. This was repeated at distances of 30, 25, 20, 15, 10, 5, 2.5, and 0.5 feet from the detectors.

4.A2 Vehicle Head Lamps (Night): This test was the same as 4.A1 but was conducted between 10:00 p.m. and 12:00 midnight.

4.B1 Frosted Incandescent (Day): A 100-watt frosted Sylvania light operating at 115 V AC was mounted in a drop-light fixture at eye level. At 35 feet from the detectors, the light was turned on and left on. Next it was turned on and off in rapid succession. The light was then waved back and forth. Finally, it was left on and carried three to four steps closer to the detectors. All of these actions were repeated at 30, 25, 20, 15, 10, 5, 2.5, and 0.5 feet.

4.B2 Frosted Incandescent (Day): This test was the same as 4.B1 except that the voltage applied to the light was reduced to 57.5 V AC.

4.C1 Rough-Service Incandescent: This test was the same as 4.B1 except a 60-watt rough service Sylvania light operating at 115 V AC was used.

4.C2 Rough Service Incandescent: This test was the same as 4.B1 except a 60-watt rough service Sylvania light operating at 57.5 V AC was used.

4.D Fluorescent Light: This test was the same as 4.B1 except that four Sylvania F40/CW fluorescent tubes were used.

4.E Electric Arc: A system producing 1,000 V DC with metal rod gapped at 1/2 inch was placed 20 feet from the detectors. Power was applied for 20 seconds. This was repeated at 15, 10, 5, 2.5, and 0.5 feet from the detectors.

4.F Vehicle Infrared Light: This test was the same as 4.A1 except red lens covers were placed over the head lamps.

4.G Sunlight: For this test the detectors were placed outside the shelter and tilted to face directly toward the sun.

4.H Ambient Light Extremes: The detectors were placed in the bed of the pickup truck parked inside the shelter. Five minutes after turning on the detectors, the truck was driven outside of the shelter into direct sunlight.

4.I Brightly Colored Clothing: A man 71 inches tall and weighing 150 pounds wore an orange safety vest and walked across the field of vision of the detectors at a distance of 35 feet. He then ran across the field of vision. This was repeated at 30, 25, 20, 15, 10, 5, and 2.5 feet.

4.J Electronic Flash: A Vivitar Model 365 electronic flash was activated 35 feet from detector. This was repeated 30, 25, 20, 15, 10, 5, 2.5, and 0.5 feet.

4.K Movie Light: This test was the same as 4.B1 except a 300-watt 115-120 V AC Sylvania flood light was connected to a drop-light cord without the reflector.

4.L Red Beacon Light: This test subjected the detectors to two different beacon lights. The first was a 120 V DC light mounted on top of a P-13 truck. The second was an aircraft anticollision beacon light, nomenclature Aircraft No. 78366, S1226B-A, FSN 6220-00-803-4610 Cont., No. DSA-400-77-C-D461, 28 V AC using two Grimes A-70798-24 28 V 40 W 8032. At 35 feet from the detectors, the lights were separately turned on and left on for 15 seconds, then moved back and forth. This was also done at 30, 25, 20, 15, 10, 5, 2.5, and 0.5 feet.

4.M Blue-green Dome Light: This test was the same as 4.L except that a 12 V dome light from a military police vehicle was used.

4.N1 Flashlight with Red Lens: In this test, a model MX993/[illegible] Fulton flashlight with a red lens, powered by two Eveready batteries, dry BA-30, NBA-030, DAAB07-82-D-G046 was used. The procedure was same as that used for 4.B1.

4.N2 Flashlight: This test was the same as 4.B1, except using the flashlight used in 4.1N1 was used without the red lens.

4.01 Reflected Light (Gloss Colors): The detectors were placed on the first level at the front of the shelter facing sunlight reflected from a multicolored sheet of Plexiglas. The Plexiglas was red (331 in.$^2$), orange (270 in.$^2$), and yellow (202 in.$^2$), and was located 35 feet from the detectors. After an initial period with fixed reflectors, the Plexiglas was rippled. The Plexiglas was then waved back and forth. This was repeated at 30, 25, 20, 15, 10, 5, and 2.5 feet.

4.02 Reflected Light (Fluorescent Colors): This test was the same as 4.01 except that the Plexiglas was painted equal parts fluorescent yellow, fluorescent green, and fluorescent orange.

4.03 Reflected Light (Glass Mirror): The glass mirror that was used measured 240-2/3 in.$^2$. The rest of the test was the same as test 4.01, except the mirror was not flexed to produce ripples.

4.P1 Chopped Light: This test used a 60-watt rough-service 115V AC incandescent light on a drop-light fixture. The chopping action was produced by a three-bladed fan driven by a .5-horsepower, 1075 RPM motor. The fan motor operated at 19 V AC, producing 72 rpm. The light was placed behind and to the side of the fan motor. This test was done at 35, 30, 25, 20, 15, 10, 5, and 2.5 feet from detectors.

4.P2 Chopped Light: This was the same as test 4.P1, except the motor operated at 22.5 V AC, producing 100 rpm.

4.P3 Chopped Light: This was the same as test 4.P1, except the motor operated at 30 V AC, producing 200 rpm.

4.Q Arc Welding: A gas powered portable Lincoln welder was operated at 300 amp to weld a 5/32-inch steel rod to a flat sheet of steel. The first part of the test was to strike an arc. The second part of the test was to run a bead for 20 seconds. This was done at 35, 30, 35, 15, 10, 5, and 2.5 feet.

4.R Acetylene Flame: A cutting torch with a flame length of 10 inches was placed 35 feet from the detectors. After the flame burned for 30 seconds, a 0.25-inch sheet of steel was cut for 15 seconds. This was repeated at 30, 25, 20, 15, 10, 5, and 2.5 feet.

4.S Security Personnel Weapons:

4.S16. M-16 rifles were positioned 90 degrees from the detectors at distances of 20, 10, 5, and 2.5 feet. Four 18-round magazines (every third round a tracer) were fired from each of the weapons. The weapons were fired individually and simultaneously on semiautomatic and full automatic settings. This test was done twice (day and night).

4.S60. M-60 machine guns were positioned 90 degrees from the detectors at distances of 10 and 15 feet. They each fired five rounds individually and then 30 rounds simultaneously. This test was done twice (day and night).

4.S79. M-79 grenade launchers were positioned 90 degrees from the detectors at distances of 1, 2.5, and 5 feet. They were fired individually, simultaneously, and in close sequence. This series was repeated three times during both day and night.

4.S38. 38-caliber pistols were positioned 90 degrees from the detectors at 1, 2.5, 3.5 and 5 feet. They were fired three times separately and three times simultaneously. The test was done twice (day and night).

4.S12. 12-gauge shotguns were positioned 90 degrees from the detectors at distances of 1, 2.5, and 5 feet. They were fired individually, simultaneously, and in close sequence. This test was done twice (day and night).

4.T Flashbulb: An M-3B flash bulb was activated at 35, 30, 25, 20, 15, 10, 5, 2.5, and 0.5 feet from the detectors.

4.U Radiation Heater (Operating at 1,000 watts): The heater was operated at 35 feet from the detectors and moved toward the detectors every 30 seconds in 5-foot increments, then moved to 2.5 feet. The test was repeated with a cone Glocoil unit operating at 115 V AC, 660 watts.

4.V Cigarette (Lighted): A lighted cigarette was held at 2.5 and 1.5 feet from the detectors.

4.W Book Match (Flare-Up): A full book of matches was ignited at 35, 30, 25, 20, 15, 10, 5, 2.5 feet, and 5 inches from detectors.

4.X Quartz Light: A quartz light, 120 V, 500T3Q/CL/U, was operated at 115 V AC in a lamp holder QF-500A floodlight, Catalog No. C5246-005A, Code KF, 500 watts. The light was positioned 35 feet from the detectors and moved toward the detectors in 5-foot increments. The light was held stationary and then waved back and forth at each position.

4.Y Black Light: This was the same test as 4X but with a black light (Tube No. Ful. 15T8B1) from a Bug Wacker insect-repelling light.

4.Z Mercury Vapor Light: This was the same test as 4X, but with a mercury vapor light (660 watts).

4.ZZ Lightning: The detectors were exposed to varied bolts of lightning strikes before and during a rainstorm. The lightning was very clear and the sky relatively cloudless for the first 20 minutes. Then the sky became dark and heavy rain followed the lightning.

The false alarm tests can be divided into four different categories. They are:

1. Light Sources and Light Reflectors
   Tests 4.A-4.P and 4.X-4.ZZ
2. Firearm Discharge
   Tests in the 4.S series
3. Other Fires
   Tests 4.Q, 4.R, 4.V and 4.W
4. Heat Sources
   Test 4.U

A listing of the individual detectors and the false alarm tests that they responded to is presented below:

| | | | | |
|---|---|---|---|---|
| UV/IR 1 | No false alarms | | | |
| UV/IR 1S | No false alarms | | | |
| UV/IR 2 | 4.C.1 | 4.R | 4.S-60-N | 4.S-38-N |
| | 4.S-12-D | 4.S-12-N | 4.W | |
| UV/IR 3 | 4.E | 4.R | 4.W | |
| UV/IR 4 | 4.R | 4.S-38-D | 4.S-12-N | 4.W |
| UV/IR 5 | 4.C1 | 4.C2 | 4.D | 4.E |
| | 4.K | 4.P1 | 4.P2 | 4.Q |
| | 4.S-16-N | 4.S-60-N | 4.S-38-D | 4.W |

UV/IR 5 responded inconsistently to the following tests:

4.I 4.S-16-D 4.S-79-D 4.S-79-N
4.S-12-N

UV/IR 5 was sensitized by the following test and false alarmed for no no apparent reason after the test was completed:

4.S-16-D

| | | | | |
|---|---|---|---|---|
| IR/IR 1 | 4.C1 | 4.C2 | 4.J | 4.K |
| | 4.L | 4.03 | 4.R | 4.S-16-D |
| | 4.S-16-N | 4.S-79-D | 4.S-79-N | 4.S-38-D |
| | 4.S-38-N | 4.S-12-D | 4.S-12-N | 4.T |
| | 4.U | 4.W | 4.X | 4.Z |
| | 4.ZZ | | | |
| IR/IR 2 | 4.R | 4.W | | |
| IR/IR 3 | No false alarms | | | |
| UV 1 | 4.B1 | 4.B2 | 4.C1 | 4.C2 |
| | 4.D | 4.E | 4.K | 4.P1 |
| | 4.P2 | 4.R | 4.S-16-N | 4.S-60-N |
| | 4.S-38-D | 4.S-12-N | 4.W | |

UV 1 had inconsistent response to the following tests:

4.I 4.S-79-D 4.S-79-N

UV 1 was sensitized by the following test and false alarmed for no apparent reason after the test was completed:

4.S-16-D

| | | | | |
|---|---|---|---|---|
| UV/UV/IR | 4.B1 | 4.C1 | 4.C2 | 4.D |
| | 4.E | 4.K | 4.P1 | 4.P2 |
| | 4.Q | 4.R | 4.S-16-N | 4.S-60-N |
| | 4.S-38-D | 4.S-12-N | 4.W | |

UV/UV/IR had inconsistent response to the following tests:

4.I 4.S-79-D 4.S-79-N

UV/UV/IR was sensitized by the following test and false alarmed for no apparent reason after the test was completed:

4.S-16-D

In general, if a detector had a tendency to false-alarm, the alarms were most likely to be in response to matchbook flareups, firearm discharge or acetylene flames. All of the detectors that responded to the firearms did so when the firearms were at a distance of 5 feet or less from the detector. With the exception of detectors UV/IR 5, UV 1 and UV/UV/IR, all of the detectors responded to the acetylene flame or the matchbook flareup at maximum distances of 10 feet, with most of the responses occurring at distances of less than 5 feet. A significant number of detectors also responded to incandescent light bulbs. Individual detectors responded to some of the different light sources or to some of the different types of fires. Most of the responses to the various light stimuli occurred at maximum distances of 5 feet, although detectors UV/IR 5, UV 1 and UV/UV/IR responded to many stimuli at 20 feet. Installation of a fire protection system which uses voting to declare a fire can eliminate many of the false alarms declared by the detectors. If a detector only false alarmed when the stimulus was very close to the detector relative to the distance between detectors, a requirement that two or more detectors declare a fire (vote) before the extinguishing agent is discharged would eliminate system false alarms, although individual detectors would nevertheless false alarm.

Detectors UV/IR 1 and UV/IR 1S gave the same responses to the false alarm stimuli. Although one cannot draw general conclusions from the small sample, it appears that the sensitivity of the detector might not affect its ability to discriminate between false alarm stimuli and real fires. There is a tradeoff, however, in that the more sensitive detector had much larger blind spots.

The IR/IR detectors as a group had the most resistance to false alarm stimuli. This does not mean, however, that IR/IR detectors are inherently less susceptible to false alarms. Detector IR/IR 1 was triggered by many of the false-alarm stimuli. Detectors UV/IR 1 and UV/IR 1S had no response to false alarm stimuli. The tests show that either type of detector can be designed not to respond to false alarm stimuli by the manufacturer. Testing would have to be conducted to verify that the instrument had been set up to eliminate response to false alarm stimuli. Another method which could be used to rule out false alarms would be to program the control box to require certain types of responses from various numbers of detectors (voting) before initiating the halon dump. Thus, those detectors which did respond to several of the false alarm stimuli during this test program might be good choices for use in the HAS FPS if they were adjusted to provide high levels of resistance to false alarms.

## 9. Operational Aircraft Test Series

The operational aircraft test series was conducted to reveal any problems that an OFD may have while operating near operational aircraft or support equipment. The tests included determining the effect of aircraft engine exhaust, navigational equipment, and radios. The tests were conducted with the detectors mounted on a horse in the same fashion as in the false alarm series. The tests are listed below with their corresponding test numbers.

<u>6.A Black Powder Cartridge Start</u>: This test was conducted at Cannon AFB with an F-111 using a cartridge engine starter type MXU 4A/A. The detectors were located 20 feet from the aircraft tail directly behind the wing. The pilot ignited the cartridge and started the engine. This test was conducted twice.

<u>6.B APU/-60</u>: The detectors were located 20 feet directly behind the portable APU at a height of 6 feet. The APU was started with the detectors looking at the exhaust.

<u>6.C1 HF Radio Tail/HF Radio Wing</u>: The detectors were placed 15 feet directly behind the F-111 aircraft tail and the HF radio transmitted for 30 seconds. The detectors were then moved to a point 20 feet directly behind the wing and the HF radio again transmitted for 30 seconds.

6.C2 Attack Radar Normal/Pencil Beam: The detectors were placed 25 feet in front of the aircraft nose, 10 feet from the centerline axis. The attack radar was operated for 30 seconds in each mode--normal and pencil beam.

6.C3 Attack Radar (5-Second Increment) TF/Situation: With the same detector positioning as in 6C2, the attack radar scope range was varied for 5-second increments at radar ranges of 2.5, 5, 10, 20, 30, 40, 80, and 200 miles. The Terrain-Following Radar (TFR) was then varied in the situation mode for the same 5-second increments and range distances.

6.C4 TF/BU Through Attack; ECM (IR Jamming): The first portion of this test is the same as 6C3, but with the TFR operating in the attack mode with back-up. Next, the Electronic Counter Measures (ECM) system of the F-111 was activated with the detector first placed 25 feet directly in front of the aircraft, then 25 feet to the side of the aircraft.

6.D Engine Exhaust: The detectors were placed 20 feet to the rear and 10 feet to the side of the F-111 aircraft. All detectors were able to view the engine exhaust. The aircraft engines were started and allowed to run for 15 seconds. Then the engines were operated at various power levels up to and including afterburner. Each afterburner stage operated for 15 seconds.

A listing of the individual detectors, showing which of the operational aircraft stimuli they responded to, is shown below:

UV/IR 1 6.D

UV/IR 1S 6.D

UV/IR 2 6.D

UV/IR 2 was malfunctioning during the following tests:

6.B 6.C series

UV/IR 3 6.D

UV/IR 4 6.D

UV/IR 5 6.D

UV/IR 5 was not used for the following tests due to power supply problems:

6.B 6.C series

UV/IR 5 was sensitized by the following test and false-alarmed for no apparent reason after the test was completed:

6.A

| | | | |
|---|---|---|---|
| IR/IR 1 | 6.C2 | 6.C3 | 6.D |
| IR/IR 2 | 6.C3 | 6.D | |
| IR/IR 3 | 6.D | | |
| UV 1 | 6.D | | |

UV 1 was unable to be used for the following tests due to power supply problems:

6.B     6.C series

UV 1 was sensitized by the following test and false alarmed for no apparent reason after the test was completed:

6.A

UV/UV/IR 6.D

UV/UV/IR was unable to be used for the following tests because of power supply problems:

6.B     6.C series

UV/UV/IR was sensitized by the following test and false-alarmed for no apparent reason after the test was completed:

6.A

All of the detectors false-alarmed during the afterburner tests. This is to be expected, since a rather large flame comes out the back of the engine during afterburner operation. None of the detectors false-alarmed during operation at nonafterburner power levels. Two of the three IR/IR detectors false alarmed when in the presence of radar, while none of the UV/IR detectors tested did so. Detectors UV/IR 5, UV 1, and UV/UV/IR were sensitized by the black powder starting cartridge, causing false alarms after the test was completed.

Once again these tests show that the OFDs should be able to be adjusted to discriminate between false and real stimuli. The problem with alarming during afterburner operation could be solved by installing a sound-level sensor which could detect afterburner operation from the high noise levels and prevent the detector from false-alarming.

The power output of the radar on the F-111 aircraft stationed at Cannon AFB has been decreased to operate at a fraction of the power level of

radar on aircraft stationed in Europe. Thus, the testing conducted during this program may not have been truly representative. These tests should be repeated on aircraft with radar operating at maximum power during qualification testing for the final fire protection system.

## H. OFD SUMMARY

The OFD testing program for the HAS project was conducted to precisely define performances and rate optical fire detectors.

As the test program evolved, it became apparent that no single detector or type of detector was necessarily the best one for the HAS application, based upon a judgement drawn from the FOV tests, false-alarm tests and full-scale system tests. The true test of applicability of a particular detector for the HAS FPS is its ability to discriminate between false-alarm stimuli and a real fire of a specified size and type in less than 5 seconds. The OFD test series showed that many detectors might be made applicable to the HAS FPS because of the internal adjustments and changes which can be made to compensate for the various false alarm stimuli or blind spots. Most detectors had an acceptable FOV.

All of the detectors had larger footprints for the 4 $ft^2$ fires than for the 1 $ft^2$ fires. This was counterbalanced, however, by an incidence of blind spots for the 4 $ft^2$ fires with 3 of the 10 detectors. This causes a potential hazard, because if a fire were to erupt directly in front of the detector, it would not be able to respond. Fire suppression systems which use these detectors will require at least one detector (two or more if a voting system is used) to cover the front plane of each detector in the detection system. However, it is felt that the blind spots may also be eliminated by internal changes to the detector, or may not occur if a growing fire, rather than an instant fire (shuttered), is used for testing.

The footprint areas for the detectors were mapped for 5- and 15-second response. All of the detectors except one had footprint area loss when the response time available to declare a fire was lowered from 15 to 5 seconds. The amount of footprint area loss was variable from detector to detector. The

one single-channel UV detector tested was only able to respond to 13 percent of the fires within 5 seconds. More testing is needed to determine if this is true for most or all UV detectors.

The testing with clean and dirty optics showed that all of the detectors will require a regular program of front lens cleaning. In the testing conducted, it was not possible to establish a time interval for all the different types of detectors, although the testing showed that single-channel UV detectors were more susceptible to footprint area changes than UV/IR or IR/IR detectors.

The test results for hot, cold, and ambient temperature conditions were variable. If the hot and cold results were compared, there was a definite trend for all types of detectors to have larger footprints under hot conditions than under cold conditions. The results for ambient conditions, however, did not fall between the results for hot and cold conditions, making it impossible to draw any other simple trends.

Mounting the detectors 10 feet above the ground generally either had no effect on the footprint area or increased it. Thus, footprint areas measured with the detectors mounted on a tripod should be reasonable to the design of systems in which the detectors are mounted on a wall.

The test of the applicability of any detection system for a particular application is its ability to avoid responding to false alarm stimuli. The detectors were subjected to stimuli from a wide variety of possible false alarm sources. The false alarm stimuli could be divided into four general groups. The first consists of various light sources, including a wide variety of light bulb types, reflected light, chopped light, and lightning. The second group includes cigarettes, matches, acetylene torches, and arc welding. The third group tested includes various security personnel weapons such as pistols, rifles, shotguns, grenade launchers and machine guns. The last type is radiation heaters.

Generally, if a detector responded to any false alarm stimuli it was to matchbook flareups, acetylene flames, or firearm discharge. A significant number of detectors also responded to incandescent light bulbs. Individual detectors responded to some of the various light sources or to the different

types of fires. As a group the IR/IR detectors had the lowest incidence of response to false alarms, although one of the IR/IR detectors responded to a wide variety of false alarm stimuli. One of the UV/IR detectors did not respond to any of the false alarm stimuli, indicating that any well-designed detector with two or more channels can have good resistance to false alarms. The one UV detector tested responded to a wide variety of false alarm stimuli and would not be considered for the HAS application.

The detectors were exposed to an operational aircraft to determine if some modes of aircraft operation would cause false alarms. They were also exposed to black powder cartridge starters, APU exhaust, radio and radar signals, and engine exhaust. A few of the detectors gave false alarms in response to black powder cartridge and the radar/radio stimuli, but in general the detectors did not respond to many of these stimuli except engine operation at afterburner power levels.

The single-band detector should not be used in the HAS because it cannot discriminate between real fires and false stimuli. It has been determined that a number of activities in the HAS could be interpreted as fires without the discriminating capabilities provided by a smart, multiple-wavelength fire detector. It has also been determined that even dual-wavelength detectors can be fooled by a combination of activities that take place in the HAS. Many of these activities and devices have been simulated in the presence of the OFDs to determine what the response of the detectors in question might be. However, resources were not available to test the OFDs against all of the potential false stimuli.

Based upon testing conducted during this program, several dual-wavelength detectors can be considered as acceptable for use in the HAS FPS if the following modifications are made:

1. The fire protection system utilizes voting by multiple detectors before declaring a fire and initiating firefighting agent dump,

2. Any significant false alarm or blind spot deficiency is corrected,

3. Some method of preventing false alarms resulting from afterburner operation is incorporated into the fire protection system, and

4. The detector meets all of the requirements of the Purchase Description (see Appendix H).

Detector UV/IR 4 is acceptable for use in the HAS FPS when the minimum distance between detectors is 20 feet. Detectors UV/IR 2 and UV/IR 3 are acceptable as tested for use in the HAS FPS when the minimum distance between detectors is 30 feet. Detector UV/IR 2 was malfunctioning during test sequences 6.B and 6.C. This detector must be tested to show that it will not respond to those stimuli.

Detectors UV/IR 1 and UV/IR 1S provide excellent false alarm rejection, but have blind spots for an instant fire of 4 $ft^2$. The latter small fire may not be significant for the particular application. Detectors UV/IR 2 and IR/IR 2 are acceptable if they can be hardened against radar. Detectors UV/IR 3 IR/IR 3 could be considered as acceptable but they had blind spots for an instant fire of 4 $ft^2$. Again, the latter may not be significant for the particular application.

The rest of the detectors are not acceptable as tested for this particular application. Detector UV/IR 5 needs refinements because of its blind spots and its response to false alarm stimuli at long distances. Detector IR/IR 1 needs refinements because of its response to reflected light at 35 feet, lightning, and radar. Detector UV 1 needs refinements because it does not respond to fires within 5 seconds and gives false alarms in response to stimuli at large distances. Detector UV/UV/IR needs refinements because of its blind spots and its response to false alarm stimuli.

These results do not imply that many detectors could not be modified or systematized and thus be made totally acceptable for the HAS application, or would not be acceptable for other applications. Since many internal adjustments can be made to OFDs, one may assume that many multiple-wavelength detectors could be adjusted and thereby be made acceptable for use in the HAS fire protection system. To ensure accurate performance for an application, validated data for the desired performance characteristics must be acquired. The results of the test program show that many well designed multple wave-

length detectors could proably be used for the HAS application if a test program was conducted to verify that adjustments had been made so that the detectors would see/ignore the appropriate type of fires (see Appendix H) and would not respond to false alarm stimuli.

The footprints covered by the detectors govern how many detectors are required to cover the entire shelter, but do not enter into the engineering decision of which detector is the best for the HAS application. Several detectors could meet the reliability and false alram criteria and would therefore be candidates for installation in the HAS. The determining factor is economic; the decision must be based upon total life cycle costs for the detection systems. Assuming that the cost per detector is approximately the same, those detectors with much larger footprints have an advantage over those with smaller footprints because their intial system costs are lower.

As previously stated, the HAS environment is extremely complex and cannot be fully defined for OFDs at this point. Before final decisions on detectors can be made, additional data must be collected for larger and growing fires. Detectors are continually being improved. The most recent FOV and false-alarm rejection data must be provided by the manufacturer and verified by the user for each particular application. Although OFDs are the best choice of fire detectors for the HAS, prior to full implementation of an automatic fire suppression system in HAS the detector system alon, including the control box, should be installed in several operational HASs and its performance monitored for some specified period of time. This would permit the detector system to be fine-tuned without risking a false dump of halon.

One source of false alarms that is present in the European HASs but which is not available to test in the United States is an IR hamming device located aboard some aricraft. This device emits high-intensity broadband IR radiation which may saturate the IR channels of a dual-spectrum fire detector. These devices are not generally operated on the ground. However, if they were operated while the aircraft were in the HAS, a false alarm might result.

Another untested factor which may affect the performance of OFDs is the high vibration and acoustic levels existing in the HAS. These may affect the ability of the OFD to discriminate between real fires and intense blackbody radiation. These high vibration and acoustic levels may also have an impact on the reliability of the OFD components.

The link between the OFDs and the actual suppression system for the HAS is the control panel. A failure in this singular component of the system could immobilize the entire fire suppression system. For this reason, thorough testing of the control panel should be conducted.

## SECTION VI

## HAS FPS TESTS, RESULTS, AND CONCLUSIONS

### A. TEST DESIGN

Three HAS FPSs from three different manufacturers were tested at the Headquarters Air Force Engineering and Services Center test site at Tyndall AFB, Panama City, Florida. The purpose of the testing was to demonstrate the performance of three different designs using commercially available fire protection equipment. The tests were designated Series A, B, and C. Appendix A contains the HAS FPS Test Plan. Instrumentation layout and data sheets are contained in Appendix B. The proprietary design and reports of each manufacturer are included in Volume III (Appendixes D, E, and F) of this report.

Tests were conducted in a two-thirds scale, third-generation hardened shelter. The shelter construction (75 feet wide by 80 feet long) was identical to operational shelters except for two modifications. The front opening to the shelter had a permanently constructed wall with two barn-type doors measuring 10 feet 3 inches by 17 feet 19 inches. The exhaust port opening did not have the blast deflection "V" construction. However, this constriction was reproduced by closing two heavy gauge steel doors 6 feet by 12 feet each to create the opening. Other minor changes were made to meet each manufacturer's system requirements, e.g., number of halon cylinders, piping, and detectors. A heavy gauge steel mockup aircraft with a footprint equaling that of an F-4 Phantom jet was utilized during each test. This mock-up was placed in the position that an operational aircraft occupies while parked in the shelter. The aircraft wings were raised to a height of 7 feet to equal the wing height of an F-15. Four wing tanks were stored along the sides of the shelter to simulate aircraft component parts actually stored in those areas. The front doors were left completely open to simulate worst-case wind conditions.

During each test series temperature, pressure, and gas concentration data were collected. The location of the gauges for each test are shown in the figure depicting each system test and instrumentation layout plans (see Appendix B). The halon concentration data collected using the Perco Analyzer

were analyzed for several potential corrections. This analysis is described under "Halon 1211 Concentration Measurements" later in this section.

Each manufacturer selected a different fire detection system, control unit, discharge mechanism, and halon distribution system, as well as different nozzles and tanks. Each system used Halon 1211 as the extinguishing agent, and was designed to suppress any fire to a height of 15 feet. Two full-scale fire scenarios designated Test 1 and Test 2, were conducted on each fire protection system.

Test 1 was a two-dimensional, 165-gallon JP-4 fuel fire. This was accomplished by tipping over three open 55-gallon fuel drums simultaneously. The drums were located at the rear of the mock aircraft and were tipped toward the front of it so that the fuel ran under the aircraft. Ignition was by three electrical glow plugs surrounded by alcohol-soaked rags located on the floor at the nose and wing tips of the aircraft. Test 2 was a three-dimensional fire that simulated an internal aircraft fire with running fuel in addition to the floor fire. In Test 2, Series A, the automatic fire detection system was disabled and the system was manually activated after a 27-second preburn on the internal fire and a 17-second preburn of the floor fuel fire. Temperatures exceeded 1900 °F and the system was incapable of total fire extinguishment. It was judged that the preburn condition exceeded the capabilities of any existing automatic fire protection system. Test 2 for series B and C tests involved 20 gallons of JP-4 placed inside the aircraft, ignited, and allowed to burn for 10 seconds before 165 gallons of JP-4 were spilled on the floor. As the fuel was spilled, the internal unburnt fuel was allowed to flow downwards to the floor. The detector units were armed prior to the point when the fuel was spilled.

## B. SYSTEM DESIGNS

For Test Series A, Company A used three dual IR detectors located in three of the four corners of the HAS. The detectors were located 15 feet above the floor. The suppression system was a manifold system. Eight cylinders of Halon 1211, pressurized to 360 $lb/in^2$ and weighing 400 pounds each, fed 20-foot headers and nozzle sections. Each cylinder had a liquid level indicator to visually give halon quantity. The remotely located control panel received the detector status and initiated the halon dump. Any two-detector voting scheme activated the solenoid valves to all cylinders. The control panel also had self-test and extinguishment inhibiting capabilities. A bell warning for fire detection and a siren for halon dump were installed at the control panel.

Company B used four UV/IR detectors for the Series B tests. Two detectors were located on each side wall of the HAS, one 8 feet from the front and the other 10 feet from the rear. The detectors were mounted 8 feet above the floor. The suppression system was a modified manifold system. Four cylinders of Halon 1211, pressurized to 360 $lb/in.^2$ and weighing 400 pounds each, fed individual header and nozzle assemblies. The halon cylinders were floor-mounted, two on each side of the HAS, with four nozzles on each side mounted 10 feet above the floor. The nozzles were spaced at distances of 1/5, 2/5, 3/5, and 4/5 the shelter length. Each cylinder had a release valve and fed two nozzles, for a total of eight nozzles. The control panel received the fire alarm signals from each detection and activated all release valves simultaneously.

Company C used eight UV/IR detectors. The HAS was divided into two zones with a detector in the corner of each zone. The suppression system was modular. Eight 250-pound and six 500-pound cylinders were used. All were pressurized to 360 $lb/in.^2$ with nitrogen. Each cylinder was mounted head down 13 feet above the floor. Two cylinders were mounted at the large door. Each cylinder had two nozzle heads connected on it. The discharge time for the 250-pound cylinders was 7 seconds. The discharge time for the 500-pound cylinders was 14 seconds. An additional 50-pound cylinder with a 30-second discharge time was used for the aircraft nacelle fire in Test 2. The control panel monitored the detector signals from the two zones. A two-out-of-four

voting scheme was used, so that any two alarming detectors from one zone would allow that zone to dump halon. One additional IR detector alarm from the other zone would allow a halon dump in that zone. The purpose of this design was to dump halon only in the zone(s) where there was a fire. This would conserve halon and also lessen the personnel egress time for a single-zone fire.

## C. TEST RESULTS

A general discussion of the performance of the three series of tests is given, followed by a detailed analysis of the Halon concentrations provided by each of the systems. The general discussion includes performance of each portion of the fire protection system. The halon concentration section quantifies the performance of the different systems to inert the shelter.

### 1. Test Series A, Test 1 - April 11, 1985

The running fuel fire was detected within 2 seconds from ignition. Within 4 seconds the fire was suppressed. High-speed film and video recording showed that the fire grew to approximately 150 $ft^2$. The maximum temperature recorded was 270 °F (see Figure B-2). No damage to shelter or aircraft was observed.

### 2. Test Series A, Test 2 - April 12, 1985

As previously mentioned, the automatic sensors were disabled to test the manual operation of the fire system, and the floor fire was allowed to preburn for approximately 17 seconds. The temperature exceeded 1900 °F. The maximum pressure reading was 0.62 over standard, or 23.9 $lb/in.^2$. The accuracy of this reading is suspect because the gauges are only rated at 500 °F. However, a 20-foot by 5-foot heavy corrugated steel overpressure door was moved outward approximately 12-15 inches during the fire burn. The manual system functioned properly but was unable to extinguish the fire permanently. Rescue vehicles were called upon to extinguish the fire. A visual inspection of the shelter exterior showed noticeable cracking in the concrete caused by the fire, although the structural integrity of the HAS was not jeopardized.

3. Test Series B, Test 1 - May 23, 1985

The fire was detected in 3 seconds. Two of the four halon cylinders discharged in less than 10 seconds. The other two cylinders discharged in the next 1.5 minutes. Maximum halon concentration measured exceeded 8 percent. The highest temperature recorded was 670 °F at 5 feet above the floor (see Figure B-5).

The fire was easily extinguished. The discharge/nozzle mechanisms on two of the halon cylinders malfunctioned. The videotape with audio and the rapidly cooling thermocouple readings indicate that the fourth halon cylinder actually discharged after the fire was extinguished. The failure analysis conducted by the vendor revealed that ball checks were missing from two of the four discharge valves.

4. Test Series B, Test 2 - May 24, 1985

As previously described, this test was conducted with a 20-gallon internal aircraft fire with a 10-second preburn and 165 gallon JP-4 running floor fire. Hoods were placed over the arcing ignition source to prevent the detectors from seeing the electric spark. The hoods may have been inadequate. Tests done in Series C showed that UV under the hoods reflected off the water on the floor. (The floor was hosed down before each test.) The instrumentation was the same as in Test 1 except the gas sample elevations were raised from 1 foot to 5 feet and from 6 feet to 10 feet.

The highest temperature recorded was 1084 °F (see Figure B-15). The fire was detected approximately 5 seconds after the ignition of the floor fire. Again the halon cylinders discharged erratically, and two of the four ball checks were missing from the discharge valves.

The fire chief at the site as well as the videotape transcription verified that the fire was not completely extinguished. AFFF from the fire truck was used to extinguish the fire. No apparent damage was done to the shelter or mock aircraft.

5. Test Series C, Test 1 - July 15, 1985

Six 20-pound evacuated tanks and five 500 cc evacuated cylinders were placed as shown in Figure B-19 to gather atmospheric samples from which halon concentration percentages were analyzed.

The fire was detected in 1 second and the small halon cylinders totally emptied in 7 seconds. The large cylinders emptied in 15 seconds. No thermocouples exceeded ambient temperature. (See Figures B-20 through B-23.)

The fire detection was 1-2 seconds faster than anticipated as a result of early UV detection from the glow plug reflecting off the water-soaked floor. The fire was extinguished with no difficulty.

6. Test Series C, Test 2 - July 17, 1985

The test was conducted in the same way as Series B Test 2, with two modifications: (1) a nacelle extinguishing unit was connected to the aircraft to extinguish the internal fire, and (2) glow plugs were replaced with manual ignition to prevent premature UV detection.

The fire was detected in 3 seconds after the floor fire was ignited. The highest temperature observed was 160 °F. The fire was easily extinguished with no damage to shelter or mock aircraft.

D. HALON 1211 CONCENTRATION MEASUREMENTS

Halon 1211 concentrations were monitored with two Perco Model 113 Gas Analyzers in addition to grab samples used only in Test Series C. These Perco instruments, which employ thermal conductivity to measure the concentration of Halon 1301 or carbon dioxide in air, can also be calibrated to determine Halon 1211 at the 0-10 percent level. Each of the three independent channels in the Perco instrument uses two glow-wire sensors functioning electrically as heated resistors in a bridge circuit. One sensor is mounted inside an air-filled "blind" cell. When this reference sensor reaches thermal equilibrium, it acts as a fixed resistance in the bridge circuit. The second glow-wire sensor is mounted inside the sample cell. When this second cell is filled with air, the temperature (and therefore the resistance) can be balanced

against the reference cell. During the sampling operation, halon enters the sample cell. Since halon has a lower thermal conductivity than air, the glow wire sensor in the sample cell increases in both temperature and resistance. The thermal conductivity of the gas mixture in the sample cell is proportional to the percentage of halon in the mixture; therefore, the difference in resistance between the sample and reference cell is a function of halon concentration.

The gas flow through the sample cell is discontinuous, so the sensor resistance is measured for a stationary gas sample. This is done to avoid the cooling effect of a moving gas. A 5-second timing cycle is used. The sample is pumped into the sample cell for 2 seconds. A valve then closes and after 3 seconds, the recorder arm, which is driven by the resistance imbalance between the sample and reference sensors, strikes the paper. The cycle then repeats.

The two Perco Analyzers were set on a table outside the test shelter. In the Series A tests, each of the three ports on each analyzer was attached to 1/4-inch ID Tygon tubing, approximately 18 feet long. The Tygon tubing was, in turn, attached to an approximately 32-foot length of 1/4-inch copper tubing (4.83 mm ID), which passed through a conduit into the shelter. This gave a total length of about 50 feet for the tubing leading to each of the six channels of the analyzers. In the Series B and C tests, the length of the copper tubing was increased to approximately 48 feet, and the length of the Tygon tubing was decreased to approximately 2 feet to give again a total length of 50 feet.

The locations of the inlets of the approximately 50-foot-long tubes for the Perco Gas Analyzers are shown in Figures B-1, B-4, and B-19, for the Series A, B, and C tests respectively. For all tests, three inlets each were located at two different heights above the shelter floor. For Test 2 of Test Series A, the levels were 5 and 10 feet. For Test 2 of Test Series C, the levels were 6 and 10 feet. In the remaining tests, levels of 1 foot and 5 feet were used. No Perco Analyzer concentration data are available for Test 1 of Test Series C.

Prior to analysis, the Perco Analyzers were calibrated, using distilled Halon 1211. Undistilled halon was found to contain sufficient oil to cause

fouling of the flow meters used in calibrating the instruments. The Perco instruments were started prior to the test and allowed to run until the measured concentration was well under 1 percent. The raw concentration data collected are presented in Tables C-1 through C-29 in Appendix C and are plotted as functions of time in Figures C-1 through C-15, to give concentration profiles. The analyses of the raw data are summarized in Tables 30-32.

The relative concentration profiles determined in Test 1, Series A seem reasonable. The concentrations and hold times at probe elevations of 1 foot are consistently larger than those at 5 feet. The faster concentration decay at the higher elevation may reflect stratification resulting from settling. The lower than calculated concentrations (Table 3) in this and certain other tests are the result of inherent errors in the sampling system using with the Perco Analyzer (see below), buoyancy, and wind effects.

The Halon 1211 concentration profile for Test 2, Series A is sharper and the fall-off is steep than expected. Moreover, the curves are anomalous in that larger concentrations are observed at 10 feet than at 5 feet at the plane nose and front right positions. These features result, in part, from the increased buoyancy and air flow experienced in Test 2, Series A, because of the large fuel burn and high temperatures which occurred. The effect on the Perco Analyzer of the increased temperature in Test 2 is shown below to be insignificant. Note that the large amounts of combustion products present in this test increase the apparent Halon 1211 concentration (see below).

In the Series B tests, as expected, the concentrations observed with the higher elevation probes were generally smaller than those observed for the lower elevations. As in the Series A tests, the Halon 1211 concentrtion profiles were sharper and fell off more rapidly for Test 2, Series B, than for Test 1 of this series. The fire in Test 2, Series B, was not completely extinguished and the highest measured temperature of 1084 °F was much larger than that observed for Test 1 (670 °F). This once again indicates that buoyancy effects cause sharper concentration profiles and faster declines.

Concentration data from the Perco Analyzer are not available for Test 1, Series C. The concentration profiles for Test 2, Series C, are not

TABLE 30. SUMMARY OF RAW PERCO CONCENTRATION DATA, TEST SERIES A.

| Probe | Height, feet | Location | Maximum concentration, percent by volume | Hold time[a] minutes seconds | Time at or above 2 percent,[b] minutes seconds |
|---|---|---|---|---|---|
| | | | Test 1 | | |
| $H_1$ | 5 | Mockup nose | 4.75 | 1:15 | 2:40 |
| $H_2$ | 1 | Mockup nose | 5.15 | 2:40 | 5:40[c] |
| $H_3$ | 5 | Right front | 4.95 | 1:30 | 2:35 |
| $H_4$ | 1 | Right front | 5.35 | 3:00[d] | 6:50[e] |
| $H_5$ | 5 | Right back | 4.40 | 1:35 | 2:25 |
| $H_6$ | 1 | Right back | 5.40 | 3:10 | 5:25 |
| | | | Test 2 | | |
| $H_1$ | 10 | Mockup nose | 3.65 | 1:00 | 1:12 |
| $H_2$ | 5 | Mockup nose | 4.35 | 0:20 | 0:32 |
| $H_3$ | 10 | Right front | 5.40 | 0:20 | 1:32 |
| $H_4$ | 5 | Right front | 5.20 | 0:18 | 1:10 |
| $H_5$ | 10 | Right back | 5.25 | 0:12 | 0:30 |
| $H_6$ | 5 | Right back | 5.40 | 0:17 | 1:20 |

[a]Time during which the Halon 1211 concentration was no less than 1 percent (absolute) of the maximum value.

[b]Time during which the Halon 1211 concentration was greater than or equal to 2 percent.

[c]Concentration dropped below 2 percent for a 30-second period during this time and then recovered.

[d]Concentration dropped below 1 percent absolute from the maximum value for 10-second period during this time and then recovered.

[e]Concentration dropped below 2 percent for a 10-second period during this time and then recovered.

TABLE 31. SUMMARY OF RAW PERCO CONCENTRATION DATA, TEST SERIES B.

| Probe | Height, feet | Location | Maximum concentration, percent by volume | Hold time,[a] minutes: seconds | Time at or above 2 percent,[b] minutes: seconds |
|---|---|---|---|---|---|
| | | | Test 1 | | |
| $H_1$ | 5 | Near mockup nose | 5.00 | 1:15 | 2:20 |
| $H_2$ | 1 | Near mockup nose | 7.10 | 2:48 | 3:35 |
| $H_3$ | 5 | Right front | 5.70 | 1:15 | 3:10 |
| $H_4$ | 1 | Right front | 7.00 | 2:45 | 3:30 |
| $H_5$ | 5 | Right back | 5.65 | 1:15 | 3:05 |
| $H_6$ | 1 | Right back | 7.50 | 2:25 | 3:30 |
| | | | Test 2 | | |
| $H_1$ | 5 | Near mockup nose | 2.40 | 0:30 | 0:10 |
| $H_2$ | 1 | Near mockup nose | 5.20 | 0:22 | 0:45 |
| $H_3$ | 5 | Right front | 5.30 | 0:18 | 0:50 |
| $H_4$ | 1 | Right front | 6.35 | 0:12 | 1:05 |
| $H_5$ | 5 | Right back | 2.85 | 0:30 | 0:22 |
| $H_6$ | 1 | Right back | 3.40 | 0:20 | 0:28 |

[a]Time during which the Halon 1211 concentration was no less than 1 percent (absolute) of the maximum value.

[b]Time during which the Halon 1211 concentration was greater than or equal to 2 percent.

TABLE 32. SUMMARY OF RAW PERCO CONCENTRATION DATA, TEST SERIES C.

| Probe | Height, feet | Location | Maximum concentration, percent by volume | Hold time,[a] minutes: seconds | Time at or above 2 percent,[b] minutes: seconds |
|---|---|---|---|---|---|
| Test 1 | | | | | |
| $H_1$ | 10 | Near mockup nose | 2.55 | 1:50 | 1:05 |
| $H_2$ | 6 | Near mockup nose | 6.50 | 0:45 | 2:45 |
| $H_3$ | 10 | Right front | 3.10 | 0:50 | 0:55 |
| $H_4$ | 10 | Right back | 3.75 | 1:15 | 2:00 |
| $H_5$ | 6 | Right back | 6.15 | 0:50 | 3:05 |

[a]Time during which the Halon 1211 concentration was no less than 1 percent (absolute) of the maximum value.

[b]Time during which the Halon 1211 concentration was greater than or equal to 2 percent.

unusual; however, the stratification appears to be more distinct. The concentrations observed at higher elevations are much less that those observed at lower elevations.

Halon measurements with the thermal conductivity detectors as utilized suffer from several potential sources of error. One possible source of error is that the temperatures of the reference and sample gases, in many cases, are not equal. In most cases the sampled gas is higher in temperature because of the presence of a fire. There are two possible effects of a temperature increase. First, the thermal conductivities of air (Reference 3) and Halon 1211 gas (Reference 4), as well as other gases, increase significantly with temperature (Figure 10). Though log/log plots usually provide the best fits to thermal conductivity data, the data in Figure 10 are very nearly linear and are fit well with the least-squares lines $k = 0.09589T + 55.14$ for air and $k = 0.04383T + 12.62$ for Halon 1211. Here k is the

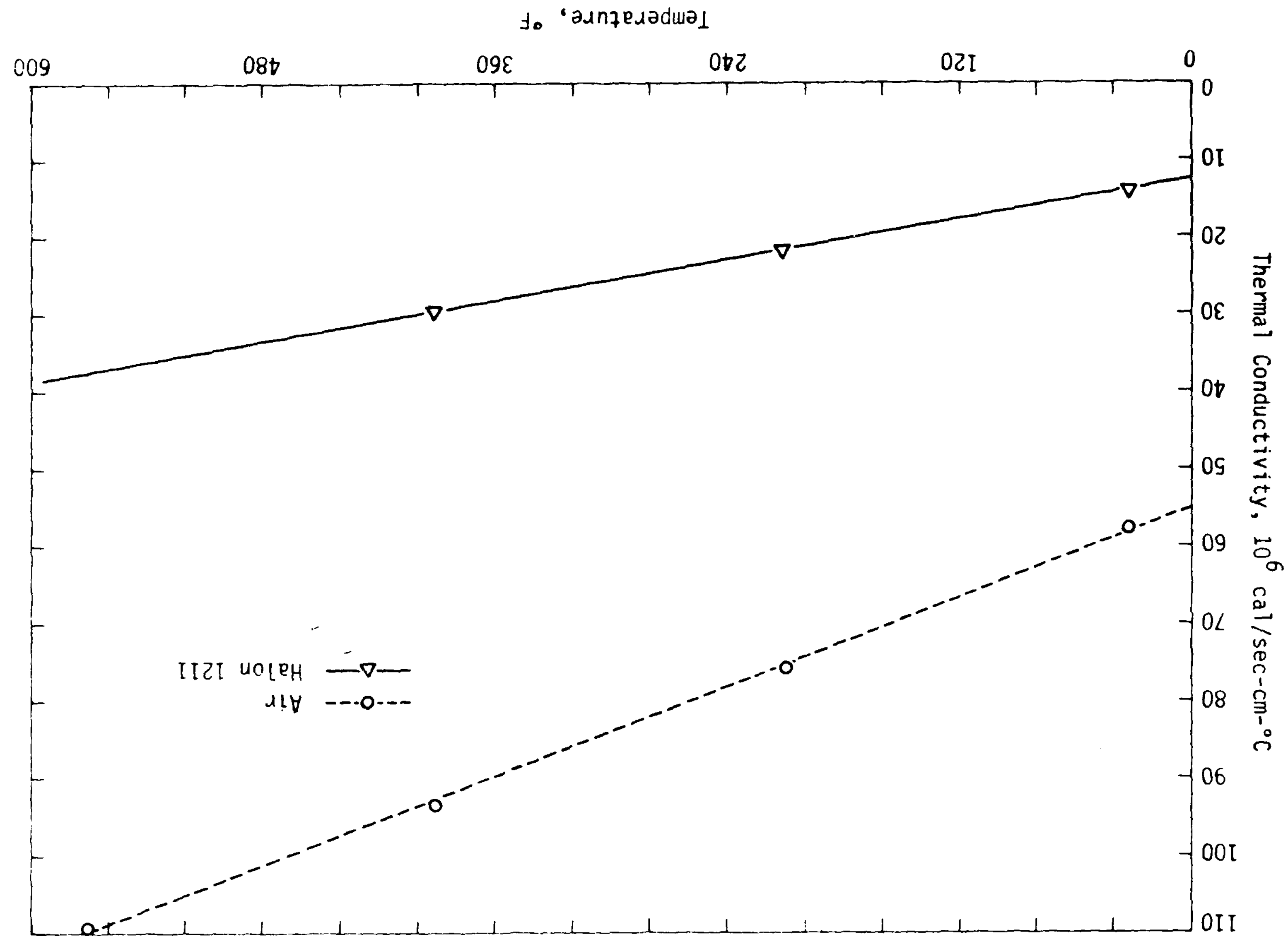



Figure 10. Temperature-Dependence of Thermal Conductivities of Air and Halon 1211.

thermal conductivity in units of $10^{-6}$ cal/sec-cm-°C and T has units of degrees Fahrenheit.

The second effect of a temperature increase is that a higher temperature for the sampled air will decrease the temperature drop between the glow wire sensor in the sample cell and the air. These two effects work in opposite directions (Equation (1)).

$$dq/dt = kA(dT/dx) \tag{1}$$

Increasing the thermal conductivity, k, increases the heat flux, dq/dt, for a given area, A, and a given temperature gradient, dT/dx. This decreases the temperature and resistance of the glow wire and gives a low reading for the Halon 1211 concentration. On the other hand, all other things being once again equal, a decreased temperature difference between the glow wire and the sampled air will decrease the temperature gradient, dT/dx, and the heat flux, dq/dt, causing a higher resistance and an unrealistically high Halon 1211 concentration. The thermal conductivities are nearly linear with temperature and can easily be calculated; however, the temperature gradient depends on the quantity $T_g$-T, where $T_g$ is the temperature of the glow wire. For very small values of $T_g$, the dependence of temperature gradient (and thermal flux) on the gas temperature is very large. On the other hand, for very large values of $T_g$ the dependence of thermal gradient on the gas temperature becomes small.

The glow wire in the Perco Gas Analyzer carried 52 milliamps of current and reaches a maximum temperature of approximately 150 °C (302 °F).* At this relatively low temperature, the decrease in thermal gradient could be large. In many cases, the temperature within the shelter during a test exceeded 300 °F (Appendix B). The temperature of the gas reaching the sample cell of the Perco Analyzer after passing through a 50-foot tube was calculated as follows.

The heat transfer coefficient, h, for pipes of length L with laminar flow can be calculated from

$$hD/k = 2(wc_p/kL)^{1/3}(\mu/\mu_{wall})^{0.14} \tag{2}$$

where D is the tube diameter, w is the mass flow rate, $c_p$ is the heat capacity at constant pressure, k is the thermal conductivity, and $\mu$ and $\mu_{wall}$ are the viscosities for the bulk gas and for the gas at the cooler wall (Reference 5). Experimental data indicate that the pipe or tubing is sufficiently long. In such a case, the fluid approaches the wall temperture asymptotically and the log mean temperature difference is no longer different from the arithmetic mean. For sufficiently long tubes, the formula

$$hD/k = (2/\pi)(wc_p/kL) \tag{3}$$

should be used (Reference 5). In transient heating over a short time, little heat may be exchanged with the outside world and the tube temperature increases. A stepwise computer calculation divides the tube into segments which are sufficiently long for the fluid to approach the average tube temperature and calculates a tube temperature profile for one package of gas at a time. This procedure demonstrates that the fluid cools rapidly and that only the first portion of the tubing heats.

The tube segment length in which the temperature approaches the wall temperature asymptotically may be estimated by combining Equations (2) and (3) and solving for the value of L. Initially, the ratio of viscosity at the segment inlet fluid temperature to the viscosity at the average wall temperature and the thermal conductivity at the average fluid conditions are needed, as Equation (4) shows.

$$wc_p/kL = \lfloor \pi(\mu/\mu_{wall})^{0.14} \rfloor^{3/2} \tag{4}$$

---

* Grassi, John, Peerless Electronics Research Corporation, personal communication, 2 June 1986.

After the length of the asymptotic tube is determined, Equation (3) is used exclusively, and both viscosity and thermal conductivity cancel. A heat balance is used to divide the gas into a number of equal portions, which are sufficiently small that the temperature of the first tube segment is raised to a limited amount.

The outlet gas temperature at each segment is adjusted to equal the average wall temperature of the segment. The average wall temperature is not adjusted since it changes very little relative to the adjustment in the gas temperature. The iteration proceeds for a single portion of gas, over several segments of tubing, until the wall temperature is changing less than 1 percent of the total allowable wall temperature change per portion of gas (now set at 10 °F). The next portion of gas is then introduced. The computer program, TEMP, is given in Table C-30 in Appendix C.

Calculations were conducted with several of the maximum temperatures given in Appendix B. Even for the worse case of 1900 °C, the gas cools to the pipe temperature in 1.25 feet.

In these calculations, it is assumed that the pipe is not heated externally by the fire owing to the short duration of the fire and the contact of the pipe with the ground. The length required to cool the gas is so short that even with an order-of-magnitude error, the gas reaches pipe temperature in less than 50 feet. Moreover, the thermal conductivity sample cell in the Perco Analyzer is mounted in an aluminum block heat sink which will also cool the gas. From these considerations, it can be concluded that the temperature of the gas sampled is, under these conditions, of little or no consequence. The lower concentrations determined for the second tests of both Series A and B, where the temperatures were larger, is apparently due to buoyancy effects (the gas is more uniformly spread throughout the HAS) rather than to effects of temperature on the thermal conductivity measurement.

A second potential source of error arises from the following. The instruments are referenced against air (approximately 21 percent oxygen, 78 percent

nitrogen, and 1 percent argon by volume, with minor amounts of water and carbon dioxide), which is treated as a single pure component with a thermal conductivity of $k_a$. The thermal conductivity, k, of the mixture of halon and air is a simple function of the mix composition. If the volume fraction and thermal conductivity of halon are X and $k_h$, the thermal conductivity of the mixture is given by

$$k = Xk_h + (1-X)k_a \tag{5}$$

Following combustion of hydrocarbon fuel, however, a significant amount of carbon dioxide and water may be present. In addition, there may be a loss of oxygen relative to nitrogen. Thus, the mixture is not a simple two-component system (Halon 1211 and air). It now contains multiple components, and the thermal conductivity will be a function of the thermal conductivity of all of the species present, which are Halon 1211, "air" (with the composition shown above), along with extra nitrogen, argon, water, and carbon dioxide.

The thermal conductivities (References 4, 6) in units of ($10^{-6}$cal)/(sec-cm-°C) at 0 °C of nitrogen (54.55), oxygen (53.05), and air (54.22) are nearly identical so that the depletion of oxygen by combustion has only a minor effect; however, the thermal conductivities of carbon dioxide (31.70) and water vapor (34.71) are intermediate between Halon 1211 (14.1) and air. Thus, the presence of a significant amount of carbon dioxide and water will lower the thermal conductivity measured and make the apparent halon concentration too high. To assess the effect, calculations of the maximum error in the halon readings were completed.

The measured burn velocity of JP-4 fuel is approximately 0.0022 gallons/ $ft^2$-sec (Reference 7). The estimated largest area covered by the 165-gallon dumps of fuel in any of the HAS/FPS tests is 500 $ft^2$. This gives a maximum

burn rate of 1.1 gal/sec. The longest time for extinguishment was less than 10 seconds, with the exceptions of Series A, Test 2, and Series B, Test 2 in which the fires were not completely extinguished. The Series B, Test 2 fire, however, was essentially extinguished in 10 seconds. It is assumed that the preburns of the small internal aircraft fire were insignificant. Thus the maximum amount of fuel burned before extinguishment, except for Test Series A, Test 2, was 11 gallons, or less than 1 percent of the total fuel. If the fuel has the general formula $C_8H_{16}$, 165 gallons contains 11.4 pound-moles and requires 137 pound-moles of $O_2$ for complete combustion. This produces 91.2 pound-moles each of $CO_2$ and $H_2O$. A 1-percent burn requires 1.37 pound-moles of $O_2$ and produces 0.912 pound-moles each of $CO_2$ and $H_2O$. With good mixing in the total HAS volume of 124,000 $ft^3$, the concentrations of the components for a 1-percent burn would be 6.14 percent Halon 1211, 0.26 percent $CO_2$, 0.26 percent $H_2O$, 1.49 percent excess $N_2$, and 92.85 percent "air," by volume.

The effect of the change in gas composition owing to combustion may be estimated as follows. The differences between the thermal conductivity in units of $(10^{-6}cal)/(sec\text{-}cm\text{-}^{\circ}C)$ at 0 °C of air and each of the other components are Halon 1211, 40.12; carbon dioxide, 22.52; water vapor, 19.51; and nitrogen, -0.33. Multiplication of each of these differences by the volume fractions gives the contribution of each component to the final thermal conductivity relative to air: Halon 1211, 2.463; carbon dioxide, 0.059; water vapor, 0.052; and nitrogen, -0.005. Summing these gives 2.566 as the total contribution of all nonair components to the thermal conductivity relative to air. Halon 1211 alone at a volume fraction of 0.0614 would give a contribution of 2.463. A comparison of the thermal conductivity contributions of 2.566 and 2.463 shows that the apparent halon concentration will be 4.3 percent higher than it should be. This figure is independent of the occupation volumes of the combustion gases and of the halon as long as the two volumes are the same. The percent error in the apparent halon concentration can be calculated by multiplying 4.3 percent by the burn percentage. For example, if 10 percent of the fuel burned before extinguishment, the percent error in the measured halon concentration would be 43 percent. These results indicate that for all but Test 2 of Test Series A, where there was a long preburn and extinguishment was not achieved, the presence of combustion products causes a negligible error in the Halon 1211 concentration measured by the Perco Analyzer.

A third potential error source in the Perco analysis results from the geometry of the collection system. The halon concentration increases rapidly upon discharge and decreases slowly as the halon leaves the shelter. This phenomenon gives a concentration/time profile. The profile measured at the Perco Analyzer will resemble the actual profile only if the sampled gas flows through the sampling line with a plug flow and if there is no diffusion. Neither of these occurs. Thus, the concentration profile is flattened and broadened so that the maximum concentration measured is too small. The integrated concentrations over time for the measured and actual profiles would, however, be the same.

The following analysis to correct for the absence of plug flow ignores the relatively small amount of Tygon tubing present and assumes that the entire sampling line consists of 50 feet of 1/4-inch copper tubing, having an inside diameter of 4.83 mm. The sampling rate for a Perco Analyzer is nominally 1.5 liters/min; however, the rate measured in laboratory tests was 2.28 liters/min. This corresponds to a bulk flow rate of 6.57 ft/s. The Reynolds number for air passing down a 4.83 mm diameter tube at this bulk flow velocity is 670. Since this number is considerably less than 2100, the point at which flow starts to become turbulent, the flow can be reliably considered laminar. Laminar flow gives a much poorer approximation to plug flow than does turbulent flow. The velocity distribution (Figure 11) across a pipe for fully developed laminar flow is given by the Hagen-Poiseville equation,

$$V = V_{max}[1 - (r/R)^2] \tag{6}$$

where $V_{max}$ is the maximum velocity, r is the radial distance from the center of the pipe, and R is the radius of the pipe (Reference 8). The bulk flow is given by

$$V_{bulk} = (1/2)V_{max} \tag{7}$$

At a bulk flow rate of 6.57 ft/s, the average transit time for the 50 feet of pipe is 7.6 seconds. The velocity and transit time of the fastest component at the center is 13.1 ft/s and 3.82 seconds. There is some unexplained discrepancy between these calculated flow parameters and those

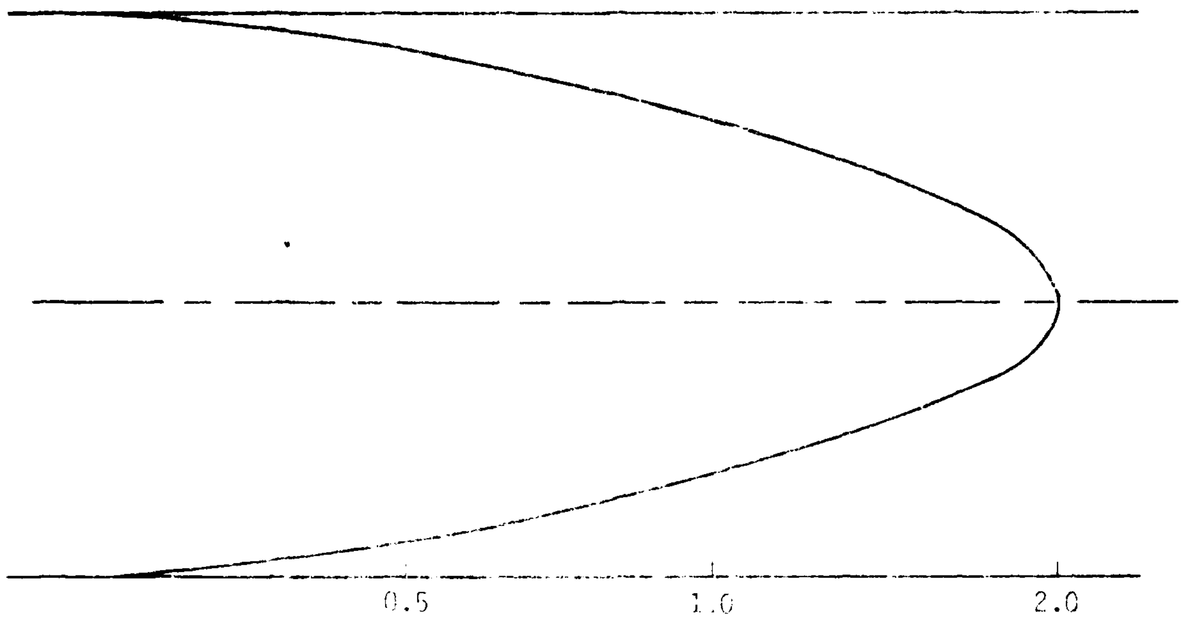



Figure 11. Velocity Distribution for Fully Developed Laminar Flow.

measured in a laboratory study on one Perco Analyzer. In that study, a lag time of approximately 23-24 seconds was determined for a 50-foot length of copper tubing connected to the Perco instrument. (Fifty-foot lengths of tubing were also connected to the other channels to correctly model the HAS tests.) Peerless Electronics Research Corporation states that there is a built-in lag time of 60 seconds required to reach 95 percent of full scale in their instrument. Measurements of the time required to record a nonzero halon concentration in our laboratory with a short, small-diameter tube gave a lag time of 6-9 seconds as the intrinsic time required to record a nonzero value. This intrinsic time explains part, but not all of the discrepancy. The remaining disagreement is probably due to the 5-second timing cycle, which can result in a 5-second error in lag-time determinations. The lag time for the HAS test is assumed to be the laboratory-measured value of 23.5 seconds (for convenience, this is taken as five timing cycles of 5 seconds each). At the pipe wall, the velocity approaches zero and the transit time increases without limit. The problem requires the use of the known velocity distribution to transform the

measured concentration profile (the raw concentration data) to give the concentration profile corrected for the absence of bulk flow. The solution follows.

Divide the pipe into concentric hollow cylinders such that each cylinder j is bounded by radii $r_j$ and $r_{j-1}$ and carries a fraction $f_j$ of the total gas with an average velocity of $V_j$. The velocities are such that the average transit time differs by 5 seconds for the contents of cylinders j and j-1. Integration of the Hagen-Poiseville equation (Equation (6)) between $r_{j-1}$ and $r_j$ gives the average velocity for the cylindrical shell bounded by these radii.

$$V = V_{max} \frac{2(r_j^2 - r_{j-1}^2) - (r_j^4 - r_{j-1}^4)}{r_j^2 - r_{j-1}^2} \qquad (8)$$

A set of velocities, $V_j$ in multiples of $V_{max}$ is first chosen to give transit times differing by 10 seconds from $t_{j-1}$ to $t_j$ for flow down the 50-foot tube. From $V_{j-1}$, $V_j$ is calculated using Equation 4. $V_0 = 0$ and $V_1$ is chosen to give a convenient fraction of material. The fraction of material contained in a hollow cylinder with inner and outer radii $r_{j-1}$ and $r_j$ is given by

$$F = (r_j^2 - r_{j-1}^2)/R^2 \qquad (9)$$

Now let $X_i$ and $Y_i$ respectively represent the concentrations on the Perco and corrected concentration profiles. Ignoring the time lag of approximately 5.58 seconds, one notes that the concentration measured by the Perco Analyzer during the first 5-second interval is given by $0.5X_1 = Y_1F_1V_1$, where the coefficient 0.5 corrects for the fact that the bulk velocity is one-half the maximum velocity. The concentration measured during the second 5-second interval is given by $0.5X_2 = Y_1F_2V_2 + Y_2F_1V_1$. In general, the measured concentration $X_i$ is given by

$$X_i = Y_1F_iV_i + Y_2F_{i-1}V_{i-1} + Y_3F_{i-2}V_{i-2} + \dots + Y_iF_1V_1 \qquad (10)$$

The subscripts on the F and V terms represent cylindrical shells in the pipe while the subscripts on X and Y represent time intervals. Zero terms resulting from flow of halon-free air in larger cylindrical shells have been omitted. These equations are a series of n linear equations in n unknowns for the first n values of Y and they can be solved by appropriate means to give the corrected concentration profile.

A program, FLOW, was written in BASIC to determine the corrected concentration profile. The program (Table C-31, Appendix C) calculates the values of $F_j$ and $V_j$ and these as coefficients of the $Y_i$ with the known values of $X$ entered as constants in the linear equations. The set of equations is solved by matrix inversion using a method similar to the Gauss-Jordan elimination method (Reference 9). The program requires about 50 minutes for 50 data points and about 8 hours for 100 items of data on a Zenitn 150 computer. Since the primary interest is in the maximum concentrations and hold and decay times attained, only the first 50 data points were used from the Perco Analyzer curves. The final corrected concentration values were then multiplied by a factor of 60/47 to correct for the calibration of the instrument to Halon 1211. This factor arises from the fact that the instrument was field-calibrated for Halon 1211 to factory specifications determined for Halon 1301. The factor 60/47 takes into account the difference in flows necessary to correct for differences in thermal conductivity between Halon 1211 and Halon 1301. The input data were taken from Tables C-1 through C-29 in Appendix C and the corrected data are presented in Tables C-32 through C-60. Summaries of the concentration profiles (Figures C-16 through C-30) corrected for the absence of plug flow are presented in Tables 33 through 35.

The correction for non plugflow gives increases of 0.3 to 1.3 percent (absolute) in the maximum concentrations observed. The peak profiles also experience some narrowing.

Correction for diffusion within the pipe during transit is much more difficult than is correction for the absence of plug flow. As the gas flows, a concentration gradient develops across the pipe. Material in the center of the pipe has the largest longitudinal velocity, and therefore responds most rapidly to concentration changes as they occur in the test chamber. As the concentration of Halon 1211 increases in the HAS, the concentration in the central region of the pipe is higher than that in the outer regions. Later, when the concentration of Halon 1211 in the HAS is decreasing, the gradient reverses. The flow which occurs to equalize the concentration causes the response curve (the measured concentration profile) to flatten. As a result, the measured concentrations are too low and the hold times are too long. As Halon 1211

TABLE 33. SUMMARY OF CORRECTED PERCO CONCENTRATION DATA, TEST SERIES A.

| Probe | Height, feet | Location | Maximum concentration, percent by volume | Hold time,[a] minutes: seconds | Time at or above 2 percent,[b] minutes: seconds |
|---|---|---|---|---|---|
| | | | Test 1 | | |
| $H_1$ | 5 | Mockup nose | 6.74 | 1:10 | 3:10 |
| $H_2$ | 1 | Mockup nose | 7.27 | 2:40 | >4:00 |
| $H_3$ | 5 | Right front | 7.13 | 1:45 | 3:10 |
| $H_4$ | 1 | Right front | 7.66 | 2:10[c] | >4:00 |
| $H_5$ | 5 | Right back | 6.49 | 1:15 | 3:07 |
| $H_6$ | 1 | Right back | 7.80 | 2.25 | 4:05 |
| | | | Test 2 | | |
| $H_1$ | 10 | Mockup nose | 5.80 | 0:20 | 1:40 |
| $H_2$ | 5 | Mockup nose | 7.07 | 0:05 | 0:40 |
| $H_3$ | 10 | Right front | 8.36 | 0:10 | 1:55 |
| $H_4$ | 5 | Right front | 8.29 | 0:10 | 1:20 |
| $H_5$ | 10 | Right back | 8.20 | 0:05 | 0:35 |
| $H_6$ | 5 | Right back | 8.24 | 0:15 | 1:25 |

[a]Time during which the Halon 1211 concentration was no less than 1 percent (absolute) of the maximum value.

[b]Time during which the Halon 1211 concentration was greater than or equal to 2 percent.

[c]Concentration dropped below 1 percent absolute from the maximum value for one 10-second period during this time and then recovered.

TABLE 34. SUMMARY OF CORRECTED PERCO CONCENTRATION DATA, TEST SERIES B.

| Probe | Height, feet | Location | Maximum concentration, percent by volume | Hold time,[a] minutes: seconds | Time at or above 2 percent,[b] minutes: seconds |
|---|---|---|---|---|---|
| | | | Test 1 | | |
| $H_1$ | 5 | Near mockup nose | 7.05 | 1:05 | 3:00 |
| $H_2$ | 1 | Near mockup nose | 10.55 | 2:10 | 3:45 |
| $H_3$ | 5 | Right front | 8.05 | 1:00 | 3:20 |
| $H_4$ | 1 | Right front | 9.87 | 2:20 | 3:35 |
| $H_5$ | 5 | Right back | 7.97 | 1:10 | 3:30 |
| $H_6$ | 1 | Right back | 10.49 | 2:05 | 3:30 |
| | | | Test 2 | | |
| $H_1$ | 5 | Near mockup nose | 3.82 | 0:10 | 0:32 |
| $H_2$ | 1 | Near mockup nose | 7.99 | 0:15 | 0:45 |
| $H_3$ | 5 | Right front | 8.21 | 0:10 | 1:00 |
| $H_4$ | 1 | Right front | 9.70 | 0:10 | 1:05 |
| $H_5$ | 5 | Right back | 4.23 | 0:20 | 0:50 |
| $H_6$ | 1 | Right back | 5.31 | 0:10 | 0:40 |

[a]Time during which the Halon 1211 concentration was no less than 1 percent (absolute) of the maximum value.

[b]Time during which the Halon 1211 concentration was greater than or equal to 2 percent.

TABLE 35. SUMMARY OF CORRECTED PERCO CONCENTRATION DATA, TEST SERIES C.

| Test 1 | | | | | |
|---|---|---|---|---|---|
| Probe | Height, feet | Location | Maximum concentration, percent by volume | Hold time,[a] minutes: seconds | Time at or above 2 percent,[b] minutes: seconds |
| $H_1$ | 10 | Near mockup nose | 3.63 | 1:15 | 1:50 |
| $H_2$ | 6 | Near mockup nose | 9.27 | 0:45 | 3:44 |
| $H_3$ | 10 | Right front | 4.72 | 0:35 | 1:25 |
| $H_5$ | 10 | Right back | 5.34 | 1:15 | 2:45 |
| $H_6$ | 6 | Right back | 8.76 | 0:40 | 3:40 |

[a]Time during which the Halon 1211 concentration was no less than 1 percent (absolute) of the maximum value.

[b]Time during which the Halon 1211 concentration was greater than or equal to 2 percent.

diffuses from parts of the flow having a higher concentration to parts having a lower concentration, air is diffusing in the opposite direction. The flux for diffusion of one gas into another is given by Fick's law,

$$J = D\,(dC/dr) \tag{11}$$

where D is the coefficient of diffusion and dC/dr is the concentration gradient in the r direction. For a two-component system (air and Halon 1211), the overall coefficient depends on both components (Reference 10).

$$D = D_1X_1 + D_2X_2 \tag{12}$$

where $X_1$ and $X_2$ are the mole fractions of Components 1 and 2. The diffusion coefficient and the mole fraction of Halon 1211 are much smaller than those of air. Thus, to a good approximation, $D = D_{air}$. The diffusion coefficient of air can be approximated from that of oxygen which is 0.178 $cm^2$/second. The concentration gradient within the pipe is not uniform, but it can be estimated by inspection of Figures C-1 through C-15. At the exit of the pipe during the rise period, concentrations of 1 percent by volume may be encountered in the center of the pipe at the time that the bulk of the gas has a zero Halon 1211 concentration. This corresponds to a Halon 1211 concentration change of greater than 1 percent over a distance of 0.24 centimeter (one-half the diameter), or a gradient of about 4 percent/centimeter. The concentration gradient is, of course, not constant with time. At the pipe entrance, it is zero. A good average number to use at the start of a test is about 2 percent/centimeter. Note that the concentration gradient for air is equal and opposite in sign to that for Halon 1211.

The mass flux is given by D (dC/dr) = (0.178 $cm^2$/sec) x (2 percent/centimeter) = 0.356 percent-centimeter/sec. During the 7.6-second calculated bulk transit time, the concentration change per unit depth is 2.7 percent/centimeter. To determine the actual concentration change, one must divide this by the thickness of the layers. For a model consisting of two shells, the layer thickness is 0.12 cm (one-fourth the diameter) giving a concentration change of 22 percent. This concentration change is, of course, unattainable since the concentrations never run this high. Moreover, this calculation does not allow for a change in the concentration gradient as diffusion proceeds. Nevertheless, it does indicate that for a worse-case scenario (the point at which the concentrations are changing the fastest was selected to obtain the concentration gradient), large fluxes can occur. For concentration profiles where the peak concentration is maintained for some time (40 or 50 seconds), the maximum concentration may be only affected slightly. On the other hand, shaper concentration/time curves may be seriously affected. Though a number of approximations were made in these calculations, it is obvious that diffusion may affect the results substantially.

A calculation of the effect of diffusion on the measured concentration profile, as done for the flow correction, would be difficult and time-consuming. To obtain some idea of the degree to which the Perco results reflect the actual concentrations, halon concentrations were measured, using grab samples in addition to the Perco Gas Analyzers for Test Series C. The grab samples were collected using evacuated steel bottles which could be opened with remotely activated solenoids following the halon discharge. Bottles of two different sizes were used. The "A" bottles were 20-pound propane cylinders and the "B" bottles were 500 $cm^3$ stainless steel cylinders. For each of the two tests in Series C, samples were collected in six "A" bottles and five "B" bottles. The bottle locations are shown in Figure B-19.

The concentrations were determined by gas chromatography employing an HP-5880A gas chromatograph with a flame ionization detector and an HP-3350 laboratory automation system integrator. The capillary column had the following characteristics: length 12.5 meters, ID 0.2 mm, film thickness 0.33 micron, phase HP-1, cross-linked dimethylsilicone, phase ratio 150, retention index 1437.5, base/acid ratio 1.4, 4600 plates/meter, Hewlett Packard part number 19091-60312. The detection limits and uncertainties in quantification of small quantities were determined for isothermal chromatography at 30 °C with a 200:1 split ratio as follows.

Chromatographic peak intensity (integrated peak area, S) is proportional to concentration (C) and injection volume (V).

$$S = KCV \qquad (13)$$

where K is a constant of proportionality. Peak areas are determined from the computerized output of the HP 5880A GC. The minimum peak integration area measurable above noise is 0.05 (units of 1/8 microvolt-seconds) with an estimated standard deviation of 0.02 (40 percent). With the instrument at its highest sensitivity (attentuation -4), an injection of 100 microliters of methanol vapor at 24 ppm yields an area of 1.20. From this the minimum peak area of 0.05 corresponds to a concentration of 1 ppm. The calculated uncertainties for various concentrations of gaseous methanol and for selected gaseous hydrocarbon standards are shown in Table 36.

TABLE 36. UNCERTAINTY IN QUANTIFICATION OF GASES.

| Concentration, ppm | Uncertainty, percent | | | |
|---|---|---|---|---|
| | Methanol | Methane | Ethane | Propane/butanes |
| 1 | 40. | ---- | ---- | ---- |
| 2 | 20. | 84. | 40. | 23. |
| 4 | ---- | 43. | 22. | 11. |
| 10 | 10. | 14. | 9. | 5. |
| 25 | 1.3 | 10. | 4. | 2. |
| 50 | 0.6 | 6. | 2. | 1. |
| 100 | 0.4 | 5. | 1. | 0.6 |

In many cases, peaks which are too small to be detected by the HP 5880A computer can still be detected visually. In this case the peak height (H) in millimeters measured from the graphical output can be used. For small, sharp peaks,

$$H = K'CV \tag{14}$$

where K' is a proportionality constant, C is the sample concentration, and V is the syringe volume. A 1 ppm solution of methanol in water gives peak heights of 6 mm and 11 mm for injection volumes of 0.2 and 0.5 microliters. It is estimated that a peak height of 3 mm could be detected. This indicates that 0.5 ppm of methanol can be detected and quantified. The uncertainty in quantification, however, is rather lage. For a peak of 3 mm, the minimum peak height, the standard deviation above noise is estimated at 1 mm (30 percent error).

This work shows that gaseous hydrocarbons and methanol down to 1 ppm can be detected and quantified.

Standards were prepared using 500 microliters of gaseous distilled Halon 1211, and the flame ionization detector response was determined as a function of concentration for standards at 5 percent (3 separately prepared samples, 4 determinations total, average area 5.645 ± 0.625 with units of 1/8 microvolt-seconds), 10 percent (7 samples, 1 determination on each, average area 10.24 + 0.66), and 15 percent (6 samples, 7 determinations total, average area 15.851 + 0.61). The oven temperature was maintained at 30 °C; the injector temperature was 200 °C. The samples were run on three different days to determine instrument stability. No variations resulting from drift were apparent. The averages and average deviations are plotted in Figure 12. The data were fit with a least-squares line to give an equation

$$C = (S - 0.18)/1.047 \qquad (15)$$

for the concentration, C, as a function of peak area, S.

The chromatographic peak areas were determined for gases from the grab samples employing the same conditions as used for the standards. The concentrations were calculated from Equation (15). The results are reported in Tables 37 and 38.

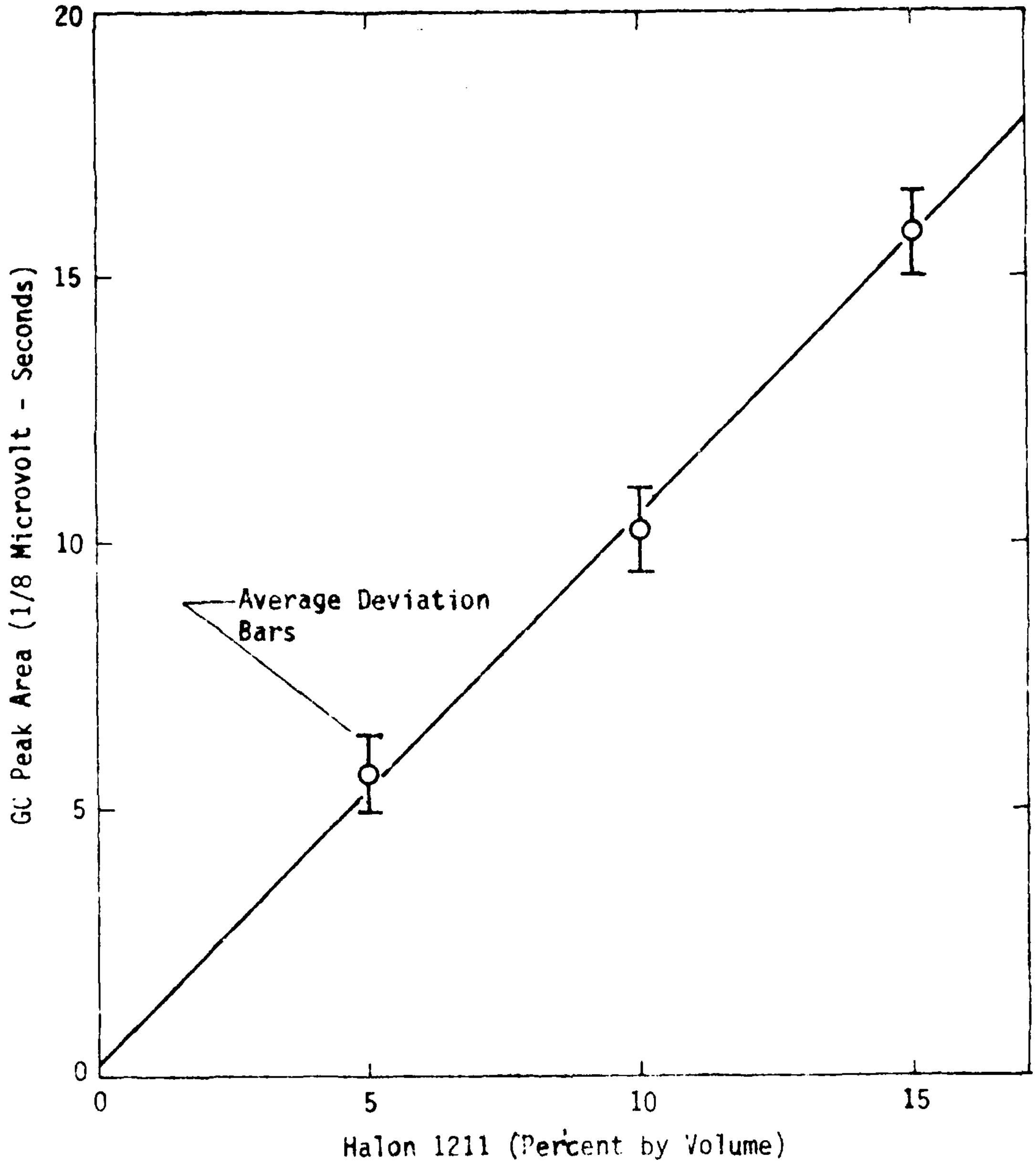



Figure 12. Gas Chromatographic Calibration Data for Halon 1211.

TABLE 37. HALON 1211 GRAB SAMPLE CONCENTRATIONS, TEST SERIES C, TEST 1.

| Bottle | Location | Sample Time,[a] min:sec | GC peak areas, 1/8 μV/second | Concentration,[b] percent by volume |
|---|---|---|---|---|
| $A_6$ | 5 feet, plane tail | 0:30 | 9.00,9.30 | 8.57 ± 0.14 |
| $A_1$ | 5 feet, right back | 0:30 | 10.37,9.06 | 9.11 ± 0.63 |
| $B_1$ | 5 feet, right back | 1:00 | 9.55,9.81 | 9.07 ± 0.12 |
| $B_2$ | 5 feet, right back | 2:00 | 3.44,3.29 | 3.04 ± 0.07 |
| $A_2$ | 1 foot, right back | 0:30 | 12.28,12.97 | 11.89 ± 0.33 |
| $A_5$ | 5 feet, right front | 0:30 | 11.09,11.48,11.63 | 10.72 ± 0.20 |
| $B_5$ | 5 feet, right front | 1:00 | 13.21,14.17 | 12.90 ± 0.46 |
| $A_3$ | 5 feet, near plane nose | 0:30 | 9.77,8.62,11.11,10.03 | 9.27 ± 0.66 |
| $B_3$ | 5 feet, near plane nose | 1:00 | 10.66,10.79 | 10.07 ± 0.06 |
| $B_4$ | 5 feet, near plane nose | 2:00 | ---[c] | ---[c] |
| $A_4$[d] | 1 foot, near plane nose | 0:30 | 13.37,12.42,14.45 | 12.64 ± 0.66 |

[a]Time from Halon 1211 dump.

[b]Calculated from averaged peak area using the graph in Figure 12. The average deviations are also given.

[c]Sample unavailable for analysis.

[d]GC showed a large amount of other components present.

TABLE 38. HALON 1211 GRAB SAMPLE CONCENTRATIONS, TEST SERIES C, TEST 2.

| Bottle | Location | Sample time,[a] min:sec | GC peak areas, 1/8 μV/second | Concentration,[b] percent by volume |
|---|---|---|---|---|
| $A_6$[c] | 5 feet, plane tail | 0:02 | 6.50,6.70 | 6.13+0.10 |
| $A_1$ | 10 feet, right back | 0:02 | 0.40,0.36 | 0.19+0.02 |
| $B_1$ | 10 feet, right back | 0:30 | 5.72,6.06 | 5.45+0.16 |
| $B_2$ | 10 feet, right back | 2:00 | 1.67,1.46,1.76 | 1.38+0.11 |
| $A_2$ | 6 foot, right back | 0:02 | 3.74,3.83,3.87 | 3.47+0.05 |
| $A_5$ | 10 feet, right front | 0:02 | 3.20,2.61,3.03 | 2.64+0.21 |
| $B_5$ | 10 feet, right front | 0:30 | 11.64,10.32 | 10.32+0.63 |
| $A_3$ | 10 feet, near plane nose | 0:02 | 1.86,1.85 | 1.60+0.01 |
| $B_3$ | 10 feet, near plane nose | 0:30 | 9.47,9.75 | 9.01+0.13 |
| $B_4$ | 10 feet, near plane nose | 2:00 | 2.56,2.46 | 2.23+0.05 |
| $A_4$ | 6 foot, near plane nose | 0:02 | 3.24,3.54,3.49 | 3.10+0.12 |

[a]Time from Halon 1211 dump.

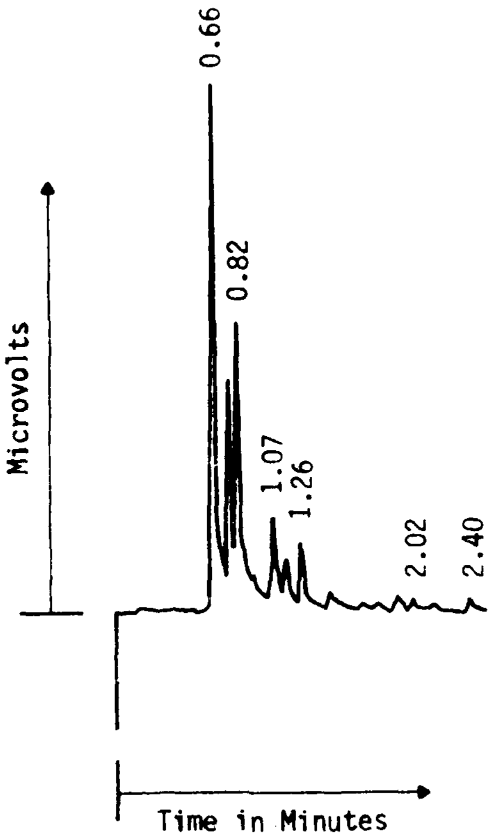
[b]Calculated from averaged peak area using the graph in Figure 12. The average deviations are also given.

[c]GC showed a large amount of other components present.

Although there are few cases where a grab sample and the Perco results can be directly compared, the large halon concentrations found in some samples indicate that the Perco analyses may give concentrations which are too low. This may be due, in part, to diffusion effects. The temperature data (Appendix B) indicate that a temperature drop occurred upon discharge in Test 1, Series C; however, the temperature decrease (to about 50 °F) would have caused only a minor increase in concentration as determined by the grab samples. The correction factor, owing to gas density changes, would be about (460 + 50) °F/(460 + 70) °F = 0.96, assuming that the chromatographic analyses were performed at 70 °F. Laboratory tests show that temperature changes caused by expansion of the sampled gas into the evacuated bottles are negligible.

The GC traces show the presence of peaks other than those due to Halon 1211. The retention times are similar for the non-Halon 1211 peaks in all of the samples; however, the intensities vary widely. Samples $A_4$ (1 foot, near plane nose, Test 1, Series C) and $A_6$ (5 feet, plane tail, Test 2, Series C) show the largest amount of material other than Halon 1211. Similar peaks were not observed for the Halon 1211 standard samples. The chromatogram for Sample $A_4$, Test 1, Series C, is shown in Figure 13.

Some of the additional peaks were identified by gas chromatography/mass spectrometry (GC/MS) on an IBM instrument employing a 14-foot, 1/8-inch, stainless steel column packed with 10 percent SP 1000 on 100/120 Supelsupport. The total ion current chromatogram and assignments for a typical sample, 0.5 mL of gas from grab sample A1, Test 1, Test Series C, are shown in Figure 14. The splitter was turned off after the principal Halon 1211 peak in order to expand the impurity peaks, and this change caused two Halon 1211 peaks to appear. The peaks were identified from the instrument library with a tentative identification of the alkane peak (from JP-4 fuel) as methylcyclohexane. Later work was performed with a Finnigan Model 4600 GC/MS with computerized spectral matching capabilities and a capillary column with the following characteristics: length, 30 m; ID, 0.25 mm; film thickness, 0.25 micron; phase, SE-54 ("nonpolar"), 94 percent-dimethyl-5 percent-diphenyl-1 percent-vinyl-polysiloxane; J&W Scientific catalog number 112-5432. That work indicated that the alkane was an alkyl-substituted cyclopropane, cyclobutane, or cyclopentane. The identification of alkanes from GC/MS data is often difficult.




| Retention Time, Minutes | Area 1/8 Microvolt/Sec | Area, Percent |
|---|---|---|
| 0.66 | 12.42 | 38.748 |
| 0.77 | 5.42 | 16.896 |
| 0.82 | 8.08 | 25.223 |
| 1.07 | 2.35 | 7.345 |
| 1.15 | 1.09 | 3.406 |
| 1.26 | 1.52 | 4.745 |
| 1.46 | 0.55 | 1.721 |
| 2.02 | 0.25 | 0.793 |
| 2.40 | 0.36 | 1.122 |

Figure 13. Gas Chromatogram, Sample A4, Test 1, Series C.

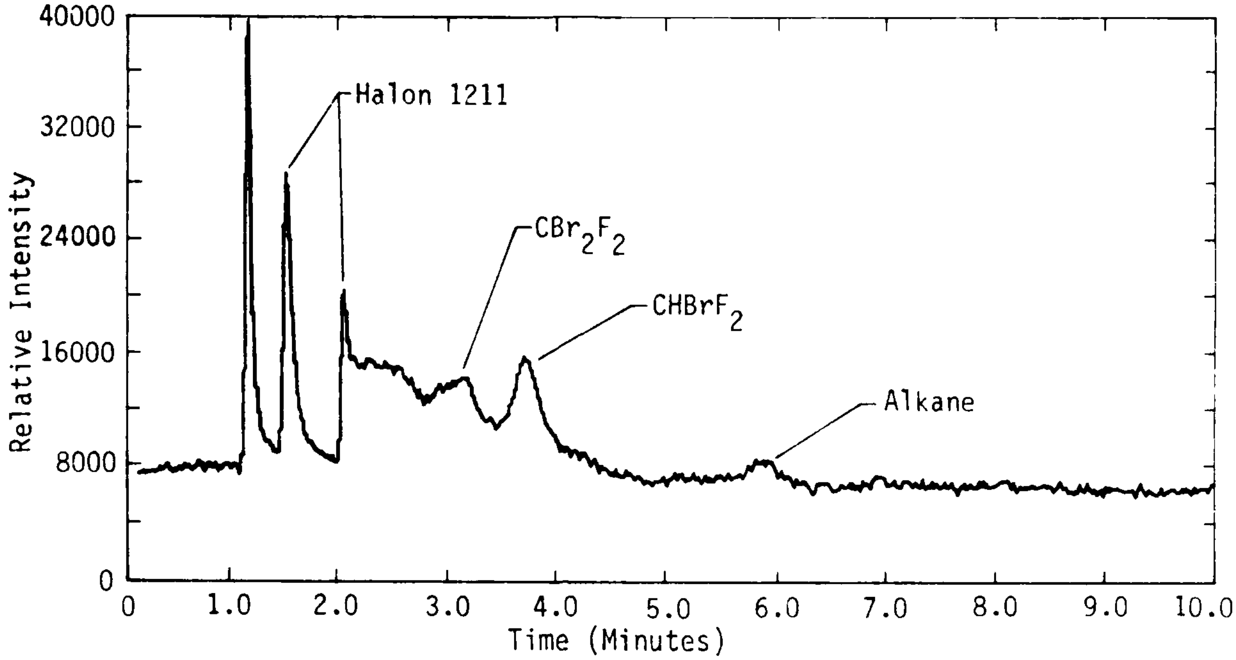



Figure 14. Total Ion Current Chromatogram for Sample A1, Test 1, Series C.

## SECTION VII
## CONCLUSIONS AND RECOMMENDATIONS

### A. CONCLUSIONS

The HAS environment and operations have been defined and the potential hazards are well understood. The challenge of developing an FPS for the HAS has been great because the HAS is a semiopen environment having numerous activities with potential for causing the FPS to false alarm. The HAS also has numerous fire hazards including potential fuel spills, munitions, high voltage electricity start carts, hydraulic carts, cartridge starts using black powder, running jet engines, static electricity, human error and wartime bombings.

To ensure fire extinguishment with minimal loss, the FPS system must be able to detect and extinguish the fire in 15 seconds or less. Yet the FPS must not respond to false stimuli such as the aircraft engine afterburner, electrical arc welding, acetylene welding, reflected sunlight, rifle fire, vehicle exhaust, lightning, lighting, matches, cigarettes, radio, radar and jamming transmissions, and radiant heaters. The research and testing conducted shows these obstacles can be overcome and the design criteria met.

#### 1. Detection

The optical fire detector has proven to be the best choice for fast fire detection without false alarms. A smart system that is microprocessor controlled using voting is needed in conjunction with the multiple-wavelength OFDs, to eliminate false alarming while maintaining fast response time. The OFD test results showed that all of the OFDs were capable of detecting 1 $ft^2$ fires. For HAS application a 1 $ft^2$ fire is not large enough to demand a system dump. Therefore the sensitivity of the system must be adjusted and shown not to respond to this small a fire.

#### 2. Extinguishing Agent

Halon 1211 has been tested at full scale under fire and no-fire conditions. It has a good throw distance, is effective in a semienclosed

area, is clean, and will not damage aircraft components. The toxicity levels are acceptable when an egress system is provided. Halon 1301 would present higher costs, including costlier logistics, and the lower toxicity of the neat agent would have to be tested for time to fire knockdown and the concentration of decomposition products.

The HAS FPS tests demonstrated that the fire protection system described in the Purchase Description is effective in extinguishing a severe HAS fire. Test Series A, Test 2 dramatically demonstrated that early detection (approximately 3 seconds) is critical. In this test, temperatures exceeding 1900 °F were reached when the extinguishing agent was dumped manually.

3. Suppression System

Three types of suppression systems were considered for the HAS: manifold, modified manifold, and modular. The modular system offers the highest degree of reliability and the most flexibility for the suppression system in a HAS. Failure of a single valve would have comparatively minimal impact on a modular system. The same failure would disable or reduce the effectiveness of a manifold system. Also, a substantial leak in a single agent tank would not necessarily compromise the extinguishing capability of the entire system. A singular style modular system can be installed into any one of the three sizes of shelters now being used, or any smaller sizes of shelters or hangars that may be designed in the future without significant hardware alterations or additions to inventory stocks. Finally, a modular system can be configured in such a way that the HAS can be divided into zones which are activated independently of each other.

4. System Performance

The control electronics play a critical role in ensuring high reliability and maintainability. High quality components should be used along with Military Standard Probability analyses to ensure high reliability. Redundant parts may be warranted. Automatic checking of the system and components should be incorporated into the HAS FPS. Automatic and remote notification of system and component status should be incorporated. A scheduled inspection and maintenance program for the OFDs and other components should be strictly applied.

### 5. System Design

The HAS FPS has been designed and tested to the conceptual prototype level. The next step is to design for developmental testing and evaluation. All concepts have been proven functionally and are state of the art. Subsystems and techniques requiring additional development are mounting techniques, control box functions and reliabilities, escape system, detector adjustments, inspection and maintenance requirements, fuel securing analysis, nacelle suppression adaptability, wind factor effects, status self-diagnostics, and remote notification.

## B. RECOMMENDATIONS

### 1. Environmental and EMI Testing

It is recommended that all subsystems of the FPS pass the applicable environmental tests of MIL-STD-810 as delineated in Appendix H, "HAS FPS Purchase Description." Furthermore, it is recommended that the FPS pass the applicable EMI tests of MIL-STD-461 and 462. The contractor should perform these tests at a qualified environmental/EMI test laboratory.

### 2. OFD Testing in Operational Environment

A major concern with the use of optical fire detectors is their inherent potential to false alarm. Even though every effort has been made to define the false alarm sources in a HAS, the possibility exists that one or more sources could not be sufficiently tested to represent the actual operational environment. A viable suggestion to avoid any oversight would be to install OFDs in operational shelters. This type of testing would remove the difficulties of simulating a HAS environment. The detectors could be installed in operational shelters. Each detector would be monitored by a data acquisition system that would record any "event."

3. Single Contractor

It is further recommended that a single contractor be made responsible for all aspects of the system. This would include not only the system design, but also the system installation and the system maintenance. The reliability and the level of confidence in the fire protection systems performance will be increased with a single contractor, total system approach. By selecting a system contractor for the HAS fire protection system program, the USAF will eliminate the need to integrate the fire protection system, oversee routine installation, maintain and service the fire protection systems, prepare integrated logistics documentation, and administer a number of contracts (instead of one). However, the USAF must ensure that more than one contractor in industry can provide such capabilities.

Another major reason for the USAF to acquire the HAS FPS as a total system is that the contractor has an inherent responsibility to assure that the FPS reliability to suppress fires, as well as not to false dump, remains at a high level. To maintain this reliability, service and maintenance must be supplied by an organization that understands the entire system, and continues to provide continuity of components and spare parts over the lifetime of the system, worldwide.

The system contractor, therefore, should qualify the FPS as a system and perform all associated program functions including integration, delivery, installation and certification of hardware. The system contractor should provide continuing maintenance of all installed systems to maintain reliability and availability of the FPS.

4. First Article Testing

It is recommended that First Article FPSs be installed in three HAS configurations housing different aircraft (e.g., F-4, F-111, F-15, F-16, and A-10). Consideration should be given to the location of the HAS and the influencing environmental conditions. For example, HASs which face directly onto the runway should be chosen to test the effect of aircraft outside the HAS. Shelters subject to high humidity or salt fog should be chosen as well.

Also, shelters subjected to the conditions described in Section II, "HAS Environment, General Description," including insect infestations, should be included.

The First Article testing should last 180 days. The halon extinguishing system need not to be activated, provided a method of recording false alarms with notification is installed. The major concern of the testing is to determine if the fire detectors are alarming in response to false stimuli. Continuous periodic inspection and evaluation should be conducted during the test period. Complete FPS evaluations should be conducted during these inspections, including fire detector self-test and inspection, system mechanical integrity, halon leakage, control electronics, back-up power, various alarms, safety devices, and sensors. Interviews with HAS operations personnel should be conducted to determine if the FPS in any way impedes the continually changing HAS day-to-day or ICT operations, e.g., multiple aircraft, pantographs, ventilation, and other storage functions.

Two areas of special testing should also be conducted during the developmental testing. The response of the fire detectors to the IR jamming device of the European-based F-111s should be evaluated. If modifications to the FPS are made to prevent responding to the IR jamming device, these modifications should be thoroughly tested and evaluated. The second area of special testing is during engine startup and operation. Vibration and performance response of the fire detectors and electronics should be evaluated under operational conditions. The response of the fire detectors to the heat and flame produced at startup should be evaluated with each of the five types of aircraft. Again, any modifications made to the FPS must be thoroughly evaluated and tested as well as installed in all First Article systems.

## REFERENCES


1. Beeson, Harold D., and Zallen, Dennis M., **Three-Dimensional Fire Extinguishants**, ESL-TR-85-62, Air Force Engineering and Services Center, Tyndall Air Force Base, Florida, 1986.

2. Zallen, Dennis M., **Potential Hazards of Using Halons for Fuel Fires Involving Munitions**, ESL-TR-81-27, Air Force Engineering and Services Center, Tyndall Air Force Base, Florida, 15 April 1981.

3. Perry, J. H., Editor, **Chemical Engineer's Handbook**, 3rd Edition, McGraw-Hill Book Company, Inc., 1950, p. 461.

4. **BCF (Halon 1211) Systems Design Manual**, ICI Americas Inc., Wilmington, Delaware, 1978, p. 10.

5. McCabe, W. L., and Smith, J. C., **Unit Operations of Chemical Engineering**, McGraw-Hill Book Company, Inc., 1956, pp. 450-452.

6. Weast, R. C., Editor, **CRC Handbook of Chemistry and Physics**, 51st Edition, The Chemical Rubber Co., Cleveland, Ohio, 1971, pp. E-2, E-3.

7. Plugge, M. A., Tapscott, R. E., Beeson, H. D., and Zallen, D. M., **Fire Suppression by Halon 2402**, NMERI WA3-26 (3.02), Air Force Engineering and Services Center, Tyndall Air Force Base, Florida, 1986.

8. Bird R. B., Stewart, W. E., and Lightfoot, E. N., **Transport Phenomena**, John Wiley and Sons, Inc., New York, 1960, p. 46.

9. Dickson, T. R., **The Computer and Chemistry**, W. H. Freeman and Company, San Francisco, 1968, pp. 141, 142.

10. Moore, W. J., **Physical Chemistry**, 3rd Edition, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1963, p. 228.




(The reverse of this page is blank.)

# APPENDIX A

## HARDENED AIRCRAFT SHELTER
## FIRE PROTECTION SYSTEM

## TEST PLAN

NOTE: The material in this Appendix is published in its original format, with no substantial text editing or changes.

AIR FORCE ENGINEERING AND SERVICES CENTER
Tyndall Air Force Base, Florida 32403

HARDENED AIRCRAFT SHELTER
FIRE DETECTION/SUPPRESSION

11 APRIL 1985

TEST PLAN

This test plan has been reviewed and approved by:

Richard N. Vickers
MR. RICHARD VICKERS
Project Officer

Everett L. Mabry
EVERETT L. MABRY, LT COL, USAF
Chief, Engineering Research Division

Joseph L. Walker
JOSEPH L. WALKER
Program Manager
Fire Technology

James R. VanOrman
JAMES R. VAN ORMAN
Dep Dir, Engineering and Services Laboratory

Harry R. Marien
HARRY R. MARIEN
Chief, Air Base Surviability Branch

[illegible]

AIR FORCE ENGINEERING AND SERVICES CENTER

| | | |
|---|---|---|
| [illegible]: | Mr. Walker | Coord Walker 4-1-85 |
| [illegible]: | Mr. Marlett | Coord [illegible] 4-2-85 |
| [illegible]: | Mr. Womack | Coord Mike Womack 4-2-85 |
| [illegible] | Lt [illegible] | Coord Everett J. Maby |
| [illegible] | Capt [illegible] | Coord [illegible] |
| PA: | Maj Heaberg | Coord [illegible] |

AIR DEFENSE WEAPONS CENTER

| | | |
|---|---|---|
| PA: | Mrs. Slicon | Coord [illegible] |
| SEF: | Mr. Parsons | Coord ________ |
| SEWS: | Mr. Trepoy | Coord [illegible] |

325 COMBAT SUPPORT GROUP

| | | |
|---|---|---|
| [illegible]: | MSgt [illegible] | Coord [illegible] 8 APR 85 |
| CES/DEF: | Mr. Stokes | Coord [illegible] |
| CTM: | MSgt Watkins | Coord [illegible] |

325 TACTICAL TRAINING WING

| | | |
|---|---|---|
| SEF: | Capt Meyer | Coord [illegible] |
| DOTS: | Capt McAl~~l~~ister | Coord [illegible] 9 APR |
| DOC: | Lt Col Gainer | Coord [illegible] 8 APR 85 |

[illegible] COMMUNICATIONS SQ (AFCC)

| | | |
|---|---|---|
| [illegible]: | Capt Bruington | Coord Michael L Bruington |

[illegible]

| | | |
|---|---|---|
| [illegible] | Maj Griffin | Coord Charles L Griffin |

TEST PLAN

FOR

HARDENED AIRCRAFT SHELTER

SUBTASK NUMBER 3.06

PREPARED BY

THE NEW MEXICO ENGINEERING RESEARCH INSTITUTE

FOR

THE AIR FORCE ENGINEERING AND SERVICES CENTER

Contents

# HARDENED AIRCRAFT SHELTER FIRE DETECTION/SUPPRESSION TEST PLAN

## Section I - Introduction

1.1 Objective - The objective of the test is to develop a Fire Detection/Suppression System for hardened aircraft shelters which will detect and suppress any anticipated fire within 30 seconds.

1.2 Background - Several hundred hardened aircraft shelters in the Air Force inventory are used to store millions of dollars in hardware. None of these shelters possesses an integrated fire protection (detection/suppression) system. A research project has been under study by the University of New Mexico Engineering Research Institute (NMERI) to analyze commercially available systems and adapt them for use in hardened shelters. A series of scale tests of different detection systems have been conducted at NMERI's laboratories. These tests indicate that detection can be accomplished within the time constraints of the shelter potential.

1.3 Scope - The Hardened Aircraft Shelter (HAS) fire protection system test will be conducted in three full-scale series. Each series will consist of two major fires and several small ones, 1, 4 and 9 foot pan fires. The specific number of pan fires will be determined by the need of each of three tested fire protection systems. It is not envisioned that more than four 1 and 4 square foot pan fires will be necessary for each test series, with one 9 square foot pan fire in each series. The major fires will be a 150 gallon horizontal and a 125 gallon vertical (internal) fire. All of the test series will be conducted inside a 2/3 scale hardened aircraft shelter, containing a mock-up of a fighter aircraft. The results of all tests will be recorded with various instruments.

## Section II - Participating Organizations

2.1 Air Force Engineering and Services Center

Project Officer - Mr. Dick Vickers

Instrumentation - SMSgt Hollopeter

Engineering Support - MSgt Lavigne

Meteorology - Capt Messina

Public Affairs - Maj Heaberg

2.2 US Army Engineer Waterways Experiment Station

Photography - Mr. Charles Ray

2.3 325 Combat Support Group

Security - MSgt Cunningham

Base Ops - MSgt Watkins

Fire Dept - Mr. Stokes

2.4 Air Defense Weapons Center

Ground Safety - Mr. Parsons

2.5 Det 5/39 ARRW (If Required)

Helicopter Support - Maj. Griffin

2.7 2021st Communications Sq

ATC - Capt Bruington

2.8 University of New Mexico Engineering Research Institute (NMERI)

Principal Investigator - Mr. Ed Schaub/Dr. Dennis Zallen
Mr. John Centrone

Construction - Mr. Bill Dees

## Section III - Description of Tests

3.1 Test Specimens - A single line drawing of the second-generation shelter is shown in Figure 1. The shelter is constructed of standard materials, i.e., corrugated steel, semicircular arches covered over with concrete. The floor is concrete with a one inch slope. A 6 inch concrete dam will be constructed around the perimeter of the shelter floor to prevent any spillage of fuel to the surrounding ground. The interior of the shelter will be lighted with ten 1500-watt lamps. The front face of the shelter is skinned with light-gauge corrugated metal. Two large hinged doors have been installed in place of the standard sliding hardened shelter doors. This modification will not affect the test results as the large fire tests will be conducted with the doors open.

3.2 Material and Structural Properties - Halon 1211 will be the suppression agent used on all fires. The detection units will utilize Infrared and Ultraviolet frequency band. JP-4 will be the fuel for all fires. Each fire will be ignited electrically.

3.3 Instrumentation and Photography - Each test will include data on temperature, pressure, velocity, and gas concentration. The data taken will be zeroed to the moment the electric signal is sent for fire ingition. The photo coverage will be both semi-high-speed and normal-speed VCR. The photography will be synchronized with the other data collection.

Still photography will be required in the form of color slides and black and white negatives to document the pretest setup and posttest damage to the structure.

3.4 Test Preparation - The general arrangement of a typical test is shown in Figure 1. Prior to each test series (3 each), the structural component of HAS facility will be checked and necessary repairs made to suport each tested fire protection system. Preparation for the individual test series will proceed as follows:

1. Contractor-installed fire protection system.

2. Install pressure gages, accelerometers, thermocouple gages, and cables. Hook up gages and test for functioning.

3. Position and protect cameras.

4. Take pretest still photographs.

5. Position fuel supply line for appropriate test.

6. Evacuate nonessential personnel to inside Third-Generation shelter.

7. Conduct final check of cameras and instrumentation.

8. Conduct countdown and ignite fuel.

9. Activate manual release of HALON if automatic release does not function.

3.6 Posttest Procedures - Immediately following each test event, the following actions shall be taken:

1. Take still photographs of damage in an undisturbed situation.

2. Drain and wash down all unburnt JP-4.

3. Remove cameras and process video immediately.

4. Check instrumentation readings.

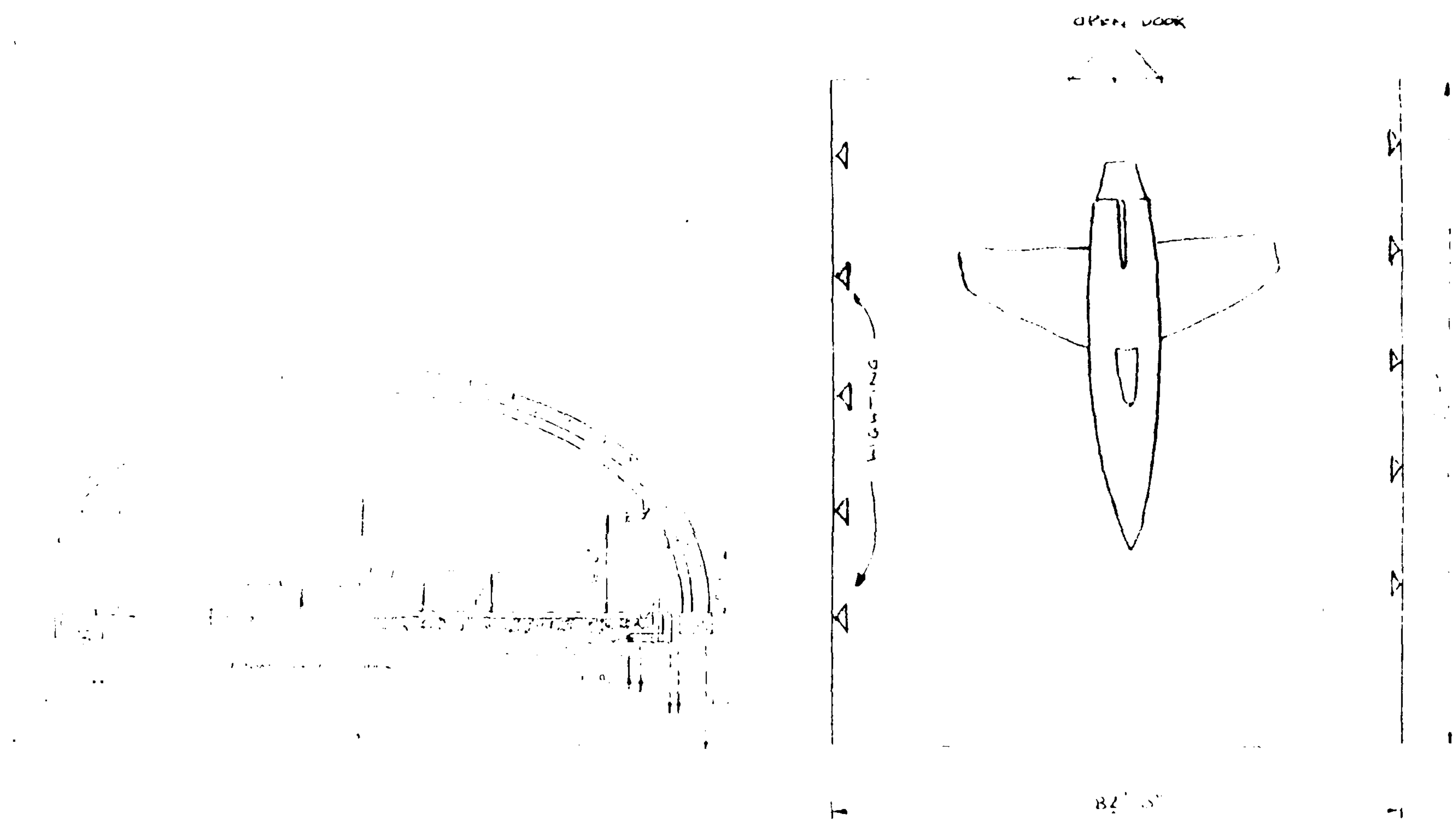



Figure A-1. Plan and Evaluation Views of Test Shelter.

## Section IV - Location and Site Description

4.1 Location - Tyndall AFB is located on the Gulf Coast of Florida, about 10 miles southeast of Panama City, on US Highway 98. The location of the test area for the Tyndall AFB Test Program is within approximately 20 acres of remote, little-used land in the SE portion of Tyndall Air Force Base FL (see Figures 2 and 3). It is approximately 7 miles from Tyndall main base, 3.6 miles from Mexico Beach (population 600) and 2.4 miles across East Bay from Allanton (population 400) in a 50-square-mile area).

4.2 Site Geology - The soil is characteristic of the coastal lowlands of Western Florida where fine gray beach sands are underlaid at variable depths by the Atronelle Formation. This material is very permeable and free-draining. The subgrade is a poorly graded sand and the water table usually occurs 2-5 feet below the surface.

The water table in the area varies with the season and may be anywhere from 4 feet to just below the ground surface. Surface drainage is normally in a southward direction into a swampy area south and east of the shelter test site. The only surface water in the immediate area is from two small borrow pits resulting from construction of the bomb damage repair runway some years ago and seasonal surface water in the swampy area southeast of the test site.

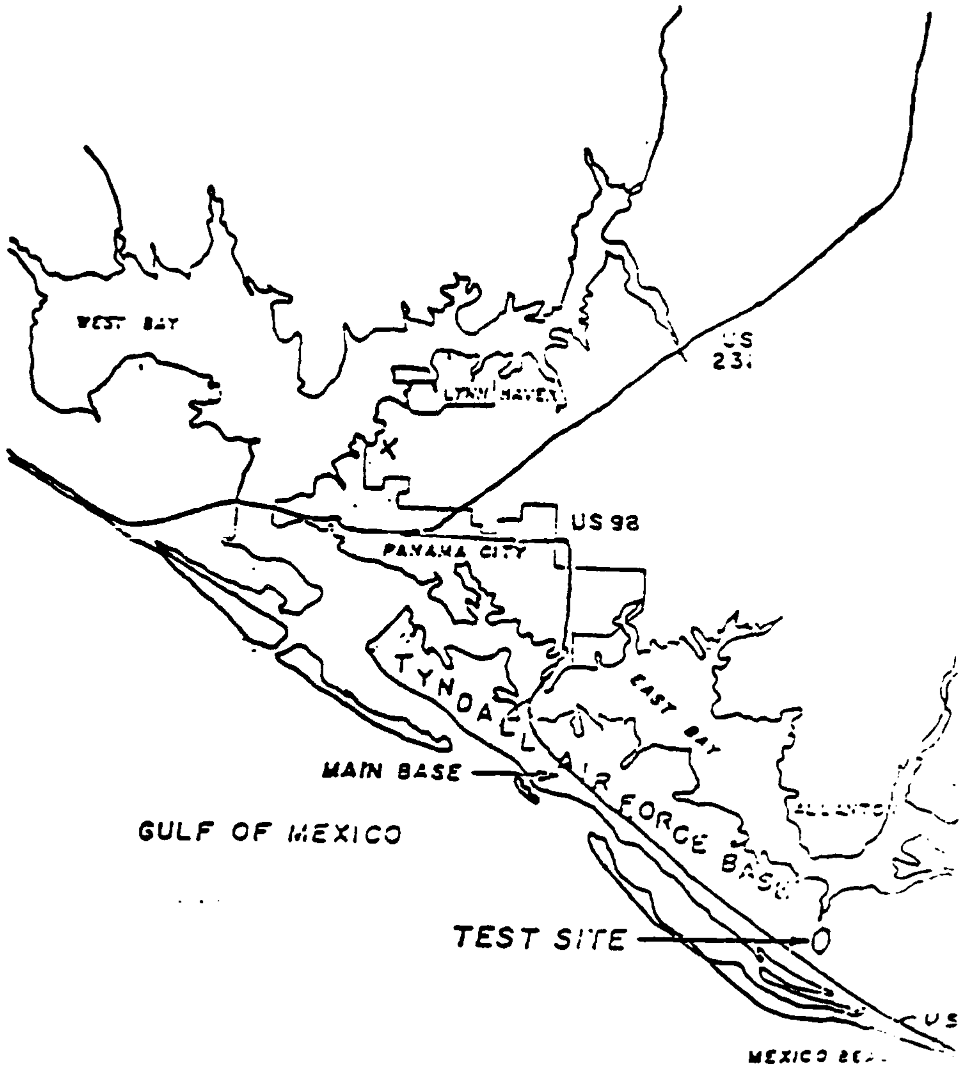



Figure A-2. Map.

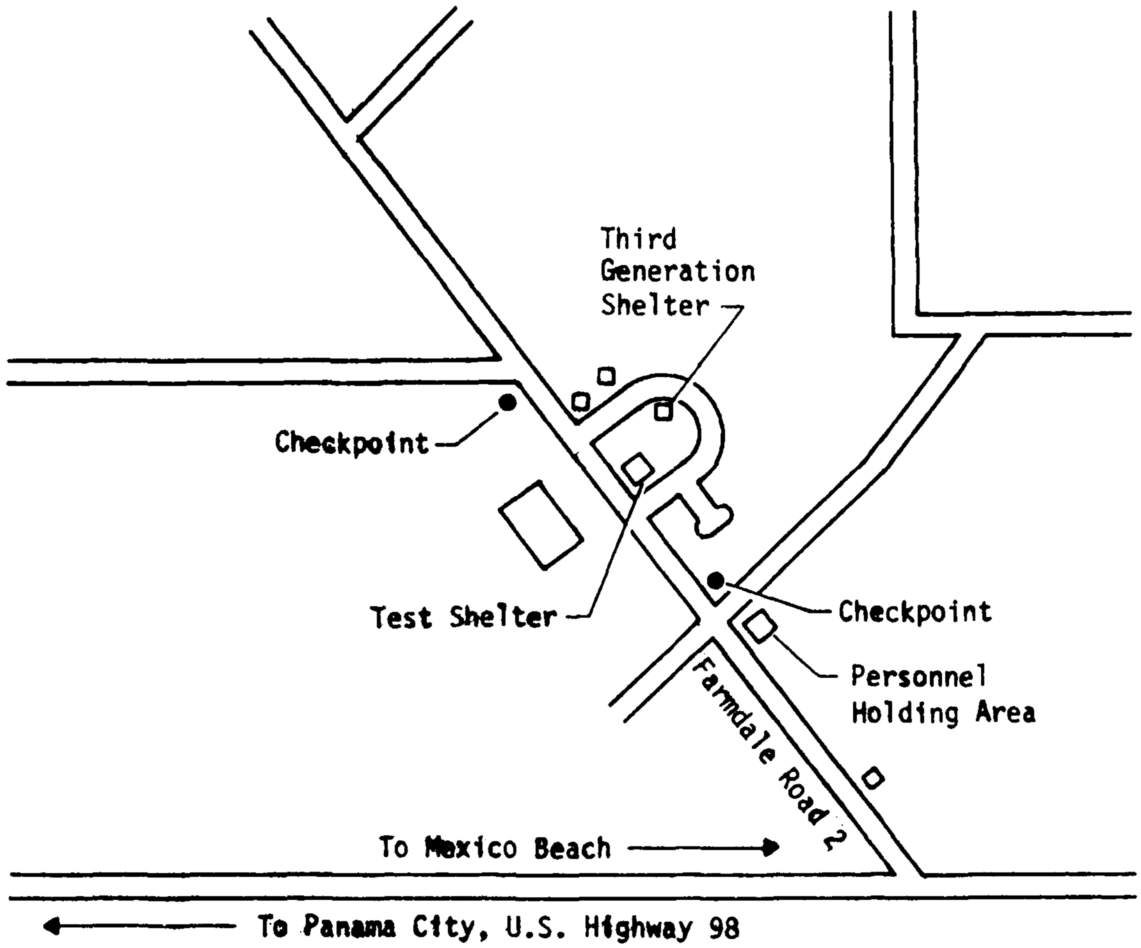



Figure A-3. Test Location Plan.

## Section V - Schedule of Events

| ESTIMATED START | ESTIMATED COMPLETION | DESCRIPTION |
|---|---|---|
| 01 Feb 85 | 01 Mar 85 | Develop test plan, coordinate contractor-installed fire protection system. |
| 01 Feb 85 | 30 Mar 85 | Prepare test site/install instrumentation. |
| 25 Mar 85 | 30 Mar 85 | Company A install fire protection system. |
| 01 Apr 85 | 05 Apr 85 | Company A conduct small pan fires 1, 4, and 9 square feet. |
| 11 Apr 85 | 12 Apr 85 | Company A conduct large vertical and horizontal fires. |
| 15 Apr 85 | 19 Apr 85 | Company A remove fire protection system. |
| 01 Apr 85 | 12 Apr 85 | NMERI collect pressure, temperature acceleration, and gas concentration. |
| 01 May 85 | 10 May 85 | Company B install system. |
| 13 May 85 | 17 May 85 | Company B small fires. |
| 22 May 85 | 24 May 85 | Company B large fires. |
| 25 May 85 | 31 May 85 | Company B remove system. |
| 01 May 85 | 24 May 85 | NMERI collect data. |
| 15 Jun 85 | 21 Jun 85 | Company C install system. |
| 22 Jun 85 | 28 Jun 85 | Company C small fires. |
| 08 Jul 85 | 10 Jul 85 | Company C large fires. |
| 11 Jul 85 | 17 Jul 85 | Company C remove system. |
| 22 Jun 85 | 10 Jul 85 | NMERI collect data |
| | 30 Aug 85 | Complete preliminary analysis of test results. |
| | 30 Sep 85 | Publish result of tests and develop a generic specification for HAS fire detection suppression system. |

## Section VI - Test Organization

6.1 Operations - The field operations organization is shown in Figure 4. Minor field modifications which affect any aspect of this project will be coordinated and approved by the Test Director.

6.2 Responsibilities - The overall responsibility for the entire test program rests with the Test Director. In addition, he will be responsible for performance of the test event's countdown coordination and procedures, and any extraordinary safety and security precautions during large-fire test days. The Test Director will delegate his authority where necessary. Specific responsibilities relative to safety, security, communication, instrumentation, photo, engineering support, weather, and community relations are contained in the appendices.

Test Organization

Project Officer

Mr. Vickers
Mr. Grimm

Tech Sup - Mr. John Centrone/
Mr. Ed Schaub

Weather - Capt Messina

Public Affairs - Maj Heaberg

Ground Safety - Mr. Parsons

Helicopter Support - Maj Griffin

| Instrumentation | Photo | Engineering Support | Security |
|---|---|---|---|
| SMSgt Hollopeter | Mr. Charles Ray | MSgt Lavigne | MSgt Cunninghai |

Figure A-4. Test Organization.

## ATTACHMENT A

### COUNTDOWN SEQUENCE OF EVENTS

1. PURPOSE: The purpose of this plan is to develop a realistic countdown sequence of events to provide positive control of all activities involved in the ignition of large horizontal and vertical fires during the test program. The specific objective of this plan is to ensure maximum protection of personnel and personal property.

2. PROCEDURES AND RESPONSIBILITIES: To minimize interference with the flying schedule, large fires will be planned for 1200 local on the morning designated as the test day. The events shown will be adhered to by the OPR during the times indicated. T-hour will represent 1200 local time on the scheduled fire burn day.

## COUNTDOWN SEQUENCE OF EVENTS

| TIME | OPERATION | OPR TO RESPOND |
|---|---|---|
| T-10 days<br>Ten days prior to ignition of large scale fire tests. | 1. Notify Base Fire Chief<br>2. Notify Base Operations | Fire Research(RDCS)<br>Test Director/Fire Chief |
| T-3 days | 1. Pre-Dry-Run Coordination Meeting | Test Director<br>Instr., Fire Chief |
| T-4 hours | 1. Check weather forecast: AFESC/WE<br>2. Ensure cameras and gauges are operational | Test Director<br>Instr, Photo |

| TIME | OPERATION | OPR TO RESPOND |
|---|---|---|
| T - 0:30 (1130 local) | 1. Establish checkpoints Alpha, Bravo, at personnel holding area. (See Figure 3 for location) | Security<br>Eng. Sup |
| | 2. One fire truck on standby. | 325 CES/DEF |
| | 3. Establish radio contact with all test project personnel to ensure hand-held radios are operable. | Test Director |
| | 4. Complete check of instrumentation and photographic equipment (final). | Instrumentation<br>Photo |
| | 5. Prohibit further traffic at checkpoints Alpha, Bravo. | Security<br>Eng. Sup |

| TIME | | OPERATION | OPR TO RESPOND |
|---|---|---|---|
| T - 0:15 (1145 local) | 1. | Ensure that all personnel and equipment are vacated from shelter. | AFESC |
| | 2. | Notify Tower that ignition will occur in 10 minutes. | Test Director |
| T - 0:05 (1155 local) | 1. | Confirm radio operation. | Control Tower<br>Safety (AFESC)<br>Security Instr.<br>Test Director |
| | 2. | Evacuate test site into third-generation shelter. | AFESC |

| TIME | OPERATION | OPR TO RESPOND |
|---|---|---|
| T - 0:00 (1200 local) | Ignite fuel. | Instr. |
| T + 0:05 (1205 local) | Notify Control Tower when fire is completely out. Release all checkpoints. | Test Director<br>Security |
| T + 0:10 (1210 local) | Inspect test site. | All |

## ATTACHMENT B

### COMMUNICATIONS PLAN

1. PURPOSE: The purpose of this plan is to develop a suitable communications network for the test. The specific objective of this plan is to provide the following:

a. Reliable communications between the test site and Tyndall Air Force Base, Florida.

b. Test site communications during construction.

c. Dependable communications on ignition day(s).

2. PROCEDURES AND RESPONSIBILITIES: Two-way radios will be the primary method of communication on the day(s) ignition is scheduled.

b. Two-way radios will be utilized on the test day to transmit all communications between the test site and all involved agencies. The following areas will be assigned hand radios: (See Figure 3 for location).

Test Director

Checkpoint Alpha

Checkpoint Bravo

Instrument Van

c. The events shown will be adhered to by the OPR during the times indicated. T-hour will represent 1200 local time on the scheduled fire burn day.

## RADIO COUNTDOWN SEQUENCE

| TIME | TEST CONDUCTOR DEMAND | RESPONSE |
|---|---|---|
| T-1:11:00 | Tyndall Control Tower (Fire Crash Net). This is the Test Conductor. Verify communications established. | Test Director verifies contact w/Control Tower |
| | The (test name) countdown sequence will commence. All Stations verify communications established via countdown network. | |
| | Safety.................................................... | Safety verifies |
| | Security Chief............................................ | Security Chief verifies |
| | Eng Sup................................................... | Engineering Support verifies |
| | All Stations | |
| | Safety.................................................... | Safety verifies |
| | Security.................................................. | Security verifies |
| | Eng Sup................................................... | Engineering Support verifies |
| | Weather verify condition "GO" and test may proceed..... | Weather verifies through Engineering Support |

| TIME | DEMAND | RESPONSE |
|---|---|---|
| | Instrumentation | Instrumentation verifies |
| | Instrumentation verify instrumentation power on line and stable in frequency and voltage | |
| | Photo proceed with camera checkout | Photo proceeds |
| | All Stations. This is the Test Conductor. The word "HOLD" from any station will stop the countdown. If necessary, transmit the word "HOLD" followed by your station (i.e., "HOLD, SAFETY") | |
| | Safety, Security proceed to clear the test area of nonessential personnel and equipment | Safety proceeds<br>Security proceeds |

| TIME | DEMAND | RESPONSE |
| --- | --- | --- |
| T-0:30:00 | All Stations at my mark, the time will be T minus 30 minutes and counting....MARK. | |
| | Safety verify test area clear of all nonessential personnel and equipment................................ | Safety verifies |
| | Security verify test area access barricades in place and Fire Trucks are on standby ........................ | Security verifies |
| | Photo verify shelter station cameras loaded to ready for test............................................... | Photo verifies |
| | Instrumentation verify manual precalibrations complete.... | Instrumentation verifies |
| | Tyndall Control Tower be advised that test will occur in 30 minutes......................................... | Test Director |

| TIME | DEMAND | RESPONSE |
|---|---|---|
| T-0:15:00 | All Stations at my mark, the time will be T minus 15 minutes and counting....MARK. | |
| | Safety verify that all support personnel are in holding area.................................................... | Safety verifies |
| | Instrumentation verify van secure, checklists complete, instrumentation systems "GO" and ready for test........... | Instrumentation verifies |
| | Tyndall Control Tower be advised that the test shelter is being filled with fuel................................... | Test Director acknowleges notification to control tower via Fire Crash Net |
| | Attention All Observers: This is the Test Conductor. The test area will be secured until declared safe by my command. (REPEAT) | |
| T-0:10:00 | All Stations at my mark, the time will be T minus 10 minutes and counting....MARK. | |
| | Stations verity communications established. | |

| TIME | DEMAND | RESPONSE |
|---|---|---|
| | Safety | Safety verifies |
| | Checkpoint Alpha | Alpha verifies |
| | Checkpoint Bravo | Bravo verifies |
| | Checkpoint Holding Area | Holding Area BRAVO verifies |
| | Eng. Sup. | Eng. Sup. verifies |
| T-0:05:00 | All Stations at my mark the time will be T minus 5 minutes and counting....MARK. | |
| | Tyndall Control Tower advised of test area | Test Director verifies "all clear" from control tower via Fire Crash |

| TIME | DEMAND | RESPONSE |
|---|---|---|
| T-0:04:00 | All Stations at my mark the time will be T minus 4 minutes and counting....MARK. | |
| | NOTE: ALL STATIONS: All commands for hold situations will be transmitted on frequency F1 (i.e., "HOLD, SAFETY") | |
| T-0:03:00 | All Stations at my mark the time will be T minus 3 minutes and counting....MARK. | |
| | Instrumentation turn off all nonessential power........ | Instrumentation Roger |
| | Instrumentation verify instrumentation power on line and stable in frequency and voltage.................... (Reset auto cal) | Instrumentation verifies |
| T-0:02:00 | All Stations at my mark the time will be T minus 2 minutes and counting....MARK. | |
| | Instrumentation verify records running and recording... | Instrumentation verifies |
| | (Auto light on?) | |
| T-0:01:00 | All stations at my mark the time will be T minus 1 minute and counting....MARK. | |
| | Tyndall Control Tower, we are at T-1 minute; ......... | Test Director verifies tower response via Fire Crash Net |

| TIME | DEMAND | RESPONSE |
| --- | --- | --- |
| T+0:00:30 | Instrumentation verify postcalibration.................. (Allow Recorders to run until T+0:01:00) | Instrumentation verifies |
| | Security maintain all barricades......................... | Security, Roger |
| T+0:01:00 | Observers stand by until my command. | |
| | AFTER AREA IS DECLARED SAFE: | |
| | Tyndall Control Tower, the test event is complete...... | Test Director advise Control Tower |
| T+0:10:00 | This is the test director. | |
| | Observers are cleared to enter the test shelter. | |

AFESC WILL BEGIN POSTTEST PREPARATIONS/OPERATIONS.

# ATTACHMENT C

## SECURITY PLAN

1. PURPOSE: Assure positive control of personnel, equipment, and vehicles arriving, leaving, and existing within the test area, and the safeguarding against theft and sabotage of government-owned equipment and materials.

2. PROCEDURES:

a. Control of personnel entering and leaving the test area - An access list of all personnel will be provided to the security chief during the countdown sequence and fuel installation. This list will be updated as required. Names of all personnel entering the site will be checked against the access list to determine admittance approval. Persons whose names are not on the access list will be denied admittance to the test area unless accompanied by or vouched for by the Test Director or his designated representative.

b. General security - At the end of each day, all trailers, tool sheds, and equipment shall be locked to preclude theft or tampering. There will be no classified material onsite.

3. RESPONSIBILITIES -

a. The 325 SPS/SPO shall conduct periodic checks of the test site area throughout the entire test series. The test site will be restricted to authorized personnel immediately before and after test fuel burn. At the time of fuel burn, Highway 98 through Tyndall AFB will not be closed to traffic.

b. All personnel are responsible for safeguarding and protecting of their individual property and the government property entrusted to them . All personnel shall report to the Test Director (or his representative) any security infraction, violation, and/or theft brought to his attention.

c. The Test Director or his designated representative is responsible for reporting, investigating, evaluating, recording, and submitting such reports as are appropriate on all security infractions, violations, or thefts. All such activity will be closely coordinated and accomplished in complete cooperation with the local and military law enforcement agencies.

# ATTACHMENT D

## SAFETY PLAN

1. PURPOSE. This safety plan establishes the safety areas for the shelter testing site and all related functions thereto, to be conducted at Tyndall Air Force Base, Florida, and identifies the agency responsible for each of these areas. All references to the test throughout this safety plan will pertain to the tests to be conducted at Tyndall Air Force Base, Florida. The detailed safety rules which are applicable to this project are documented herein. Before any fire testing can be conducted at Tyndall Air Force Base, Florida, the Base Fire Chief must be notified and his approval received. The following safety documents are applicable to this test:

AFOSH Standards

AFR 127-4

2. OVERALL SAFETY RESPONSIBILITY. AFESC/RDCS as Test Director is responsible for enforcing the overall safety program for the test. The Base Fire Chief or his designated representative is the safety officer during all actual fire burns . The Test Director is the safety officer for all other events at the test site. The Test Director will maintain close coordination with the Air Defense Weapons Center Ground Safety Officer on all safety matters.

3. SAFETY AREAS. The safety requirements of the test have been divided into three separate and distinct areas to facilitate the establishment of specific requirements for the different areas of operation. The three areas of safety requirements are divided into three areas as follows:

a. General Safety.

b. Construction Safety.

c. Fire Safety.

4. GENERAL SAFETY. The responsibility for general site safety resides with AFESC. The authority to execute specific safety directives is delegated to the Test Director. The Public Affairs Office (AFESC/PA) is responsible for notification and publicizing the test (when applicable).

a. Safety Briefing. The Test Director will brief all AFESC personnel and/or supervisors of construction crews on the safety hazards existing within the test site. Supervisors will, in turn, brief their personnel on these hazards.

b. Visitors. Visitors shall not be allowed at the test site without approval of the Test Director or his authorized delegate. Visitors shall be instructed on applicable area safety regulations.

c. Individual Safety Responsibility. Careful attention to the hazards on a construction site and the potential hazards involved in work dealing with fire must be stressed in all levels of responsibility. The purpose of the safety rules outlined herein is to present the most important elements in setting controlled fires and construction. These rules do not cover all the possible hazards or safety precautions necessary at the site. As new problems arise, new safety measures will be established to cope with them. In the interim, common sense must be applied to ensure that safety prevails. This entire Safety Plan must be closely followed by all personnel and enforced by all supervisors. The procedures contained herein shall be accepted as minimum standards until such time as the Test Director, with the concurrence of the Base Fire Chief, authorizes deviation therefrom.

d. Vehicles. Speeds shall not exceed 20 mph when driving on unpaved roads. Seat belts will be used at all times while vehicles are in motion. Speed within the construction area of the test site shall not exceed 5 mph. When a vehicle is parked, the hand brake will be set and the transmission put in park or reverse.

e. Accident Reporting (Emergency):

(1) Scope. This standard procedure is intended as a guide to ensure expedient handling and care of personnel injured in an accident or disaster. All "post-emergency" reporting and investigation of an accident will be performed in accordance with application Air Force regulations and is not considered to be within the scope of this standard procedure.

(2) Responsibility. Every person involved in this program must be completely familiar with the emergency reporting procedures established by this plan and must implement these procedures immediately in the event of an accident. The Test Director must familiarize all supervisors with this standard procedure. The supervisor must familiarize subordinate personnel with the procedures established by this plan.

(3) Emergency Reporting Procedures. In the event of an accident at the shelter test site, the following procedures will be followed:

(a) The senior supervisor at the scene of an accident will direct appropriate first aid. Caution will be exercised to prevent aggravation of an accident-related injury.

(b) Tyndall AFB Hospital Ambulance Service will be immediately notified by calling Extension 2333. The nature of the accident, including apparent condition of injured personnel and the location of the test site, will be reported to the medical personnel. The Test Director or, in his absence, the Senior Supervisor, shall determine whether to attempt transfer of the injured to a hospital or to request emergency ambulance support.

(c) The Test Director or, in his absence, the Senior Supervisor, shall determine the seriousness of an accident. If the accident is not serious enough to require emergency hospitalization or ambulance service, the injured person will be taken to a doctor or hospital by normal means of transportation.

f. First Aid. An adequate supply of first-aid items will be maintained at the site. These items will be properly stored and periodically inspected to ensure their adequacy in case of an emergency.

g. Snakes. Personnel will be on the alert at all times for rattlesnakes on the test site. Particular caution will be used when moving stacks of construction material.

5. CONSTRUCTION SAFETY. Refueling of equipment will be done at the fuel storage area. Equipment shall be grounded during refueling. No smoking will be permitted in the fuel storage area and proper signs shall be erected to remind approaching persons of the danger.

a. Heavy Equipment Operation. Heavy equipment operators will exercise extreme care in operating their equipment to ensure their safety and that of personnel working within the construction area. No repair or adjustment shall be attempted while the equipment is running or in motion.

b. Fire Prevention Reporting and Emergency Procedures. This paragraph defines the responsibility for fire prevention and reporting procedures related to the test.

(1) Responsibility. The Test Director will be responsible for the implementation of the procedures established by this plan. All onsite personnel must be completely familiar with these procedures to ensure proper response to an emergency.

(2) Fire Prevention Procedures. The procedures listed below are to be followed in an effort to reduce chances of an uncontrolled fire.

(a) One fire truck will be on standby near the test shelter.

(b) The Test Director shall instruct all personnel on the procedures to follow in case of fire, and the location and use of available fire extinguishers.

(c) All engines shall be shut down with ignition off, before and during refueling. Care must be exercised to ensure that the equipment is not so hot as to ignite fuel if it should be spilled during the refueling operation. Rubbish, waste, and industrial residue will be placed in metal drums, and removed from the site when or prior to the time drums are full.

(d) Good housekeeping is essential to fire prevention. Oil-soaked, greasy, and paint-soaked rags will be deposited in the same cans. All cans will be equipped with tight-fitting or self-closing lids.

(3) Filling Halon Cylinders. The procedures to be followed in the handling and charging of test Halon cylinders are:

(a) Two personnel will be present during all Halon transfer operations.

(b) The transfer process will occur at Base Fire Station number one.

(c) Only three each of 1500-pound Halon supply cylinders will be moved to Fire Station One at a time. The empty cylinders will be turned in to Base Supply.

(d) Movement of the filled (transferred Halon) cylinders will be conducted in accordance with esablished safety procedures and regulations. These cylinders will be stored in the Third Generation shelter unless off-loaded and placed in position in the test HAS.

## ATTACHMENT E

### ENGINEERING SUPPORT PLAN

1. PURPOSE: This plan defines procedures and responsibilities for providing engineering support for this test program.

2. PROCEDURES: The descriptions of the test specimens, test preparation, and posttest procedures are contained in Section III. The engineering support section is involved directly or indirectly in most of this effort.

3. RESPONSIBILITIES: The engineering support section, in conjunction with construction personnel, will:

a. Move and install mock-up aircraft from fire pit to test Hardened Aircraft Shelter (HAS).

b. Install fuel storage and transfer system

c. Construct curbing, doors, and drain caps in HAS.

d. Install instrumentation cable duct from test to Third-Generation Shelter.

e. Provide electrical support, including lighting for inside the HAS.

f. Provide equipment support, as necessary.

g. Collection of test data: pressure, temperature, acceleration and gas concentration.

i. Miscellaneous items as the need arises.

ATTACHMENT F

INSTRUMENTATION PLAN

1. PURPOSE: This plan describes the procedures and responsibilities for instrumentation and data collection for this test program.

2. PROCEDURES: For each of the tests, over-pressure, acceleration, temperature, and gas concentration be will collected in the HAS structure. The instrumentation layout, gage descriptions, and locations are furnished separately.

3. RESPONSIBILITIES:

a. The instrumentation section is responsible for the entire data acquisition process, including:

(1) Recording

(2) Digitization

(3) Quality assessment

(4) Initial plotting

(5) Corrections

(6) Analysis of results

b. AFESC will provide and/or install

(1) The gages and cable which will be provided by the New Mexico Engineering Research Institute (NMERI).

(2) Personnel support for system setup and operation.

ATTACHMENT G

## PHOTOGRAPHIC SUPPORT PLAN

1. PURPOSE: Both still and motion pictures are needed to provide documentary records of the test. Such records include coverage of the undisturbed site, construction and progress, and other areas of general interest. Also required is technical data photography showing results of the test events. This plan provides procedures and responsibilities for the photographic support needed for the Hardened Aircraft Shelter (HAS) Detection/ Suppression.

2. PROCEDURES:

a. Cameras will be located in the northwest and southeast corners of the HAS. They will be mounted approximately 20 feet high. Camera locations for each of the events shall be documented in the results of each test series.

b. Cameras in the test structure will record the generated environment. Camera speeds will be real time for VCRs and 200 frames/sec for 16 mm. Protection for these cameras will be the responsibility of the supplier. The cameras will be installed so that they may be remotely operated from Third Generation Shelter.

c. The Test Director will edit all motion coverage. All film and prints must be labeled. Date, time, location, and event number or subject title must be included in at least one view of each scene or item. Photo records of site operations and construction will be maintained by the Test Director.

3. RESPONSIBILITIES:

a. AFESC will furnish and install (as required):

(1) Photo Platforms.

(2) Power for cameras and lighting.

(3) Power cable.

(4) Technical still photography during construction.

b. WES will provide:

(1) Cameras, film and timing generators, control cable, any lighting in addition to installed shelter lighting.

(2) Switch closure (relays) with desired timing for cameras start.

(3) Photographers to set up, take down, and care for cameras and film.

(4) Technical still photography before and after each test.

(5) Processing, printing, and editing of film.

(6) System check out and operation before each test series.

c. AFESC and WES will work closely together to provide the following for briefings and reports:

(1) Edited compilation of film from each test.

(2) As-built data for all photo coverage.

ATTACHMENT H

# METEOROLOGICAL SUPPORT PLAN

1. PURPOSE: This plan describes procedures and responsibilities for the meterological support needed for the Hardened Aircraft Shelter Fire Detection/Suppression Test. Coordination of severe weather forecasts and climatological changes is required to assure uniformity of test series.

2. PROCEDURES:

a. AFESC/WE personnel, through Engineering Support, will be in direct contact with the Test Director during each test series to provide "standard" weather and forecasts. Forecasts and/or observed weather will be provided to the test director at T-4:00 on each large fire test day. Point weather warning (for location 29°[illegible]'[illegible]" North latitude, 85°28'35" West longitude) of thunderstorms within [illegible] nm will be provided to the Test Director with a minimum of 3[illegible] minutes lead time. The means of transmission will be by phone to Engineering Support (2914) then radio contact to the test site.

3. RESPONSIBILITIES:

a. The Test Director will provide AFESC/WE with up-to-date test event schedules, and provide the communications link with the Test Conductor on each large fire test day.

b. AFESC/WE will provide/arrange for climatological studies, weather advisories and operational weather.

c. NMERI will operate a limited weather station near the test site. Data such as wind speed, wet-and dry-bulb temperature will be collected.

ATTACHMENT I

# COMMUNITY RELATIONS PLAN

1. PURPOSE: This plan describes the actions needed to provide unclassified information on the Hardened Aircraft Shelter Fire Test to residents and officials of nearby communities and to bona fide new media representatives. The impact of additional personnel involved with the Tyndall AFB Test Program on the communities near the test area may arouse interest and possibly some misgivings. Therefore, only information which addresses these concerns should be released. Where possible, only necessary test information should be provided bona fide news media.

2. PROCEDURES:

a. News media representatives will be allowed to be present for the complete test series, but must remain at the safe [illegible] area.

b. The use of nongovernment aircraft for news media coverage of the test event will not be allowed. The test site is within Government-restricted airspace.

c. If practical, coordination of test schedules with the local community will be effected before each event. Information about the program can be accomplished through community or special group briefings, personal contacts, and news releases to the local news media.

3. RESPONSIBILITIES:

a. News releases and community relations visits in connection with the Test Program will be the responsibility of AFESC/PA.

b. AFESC will coordinate releases to local media or media visits relating to this project with ADWC/PA.

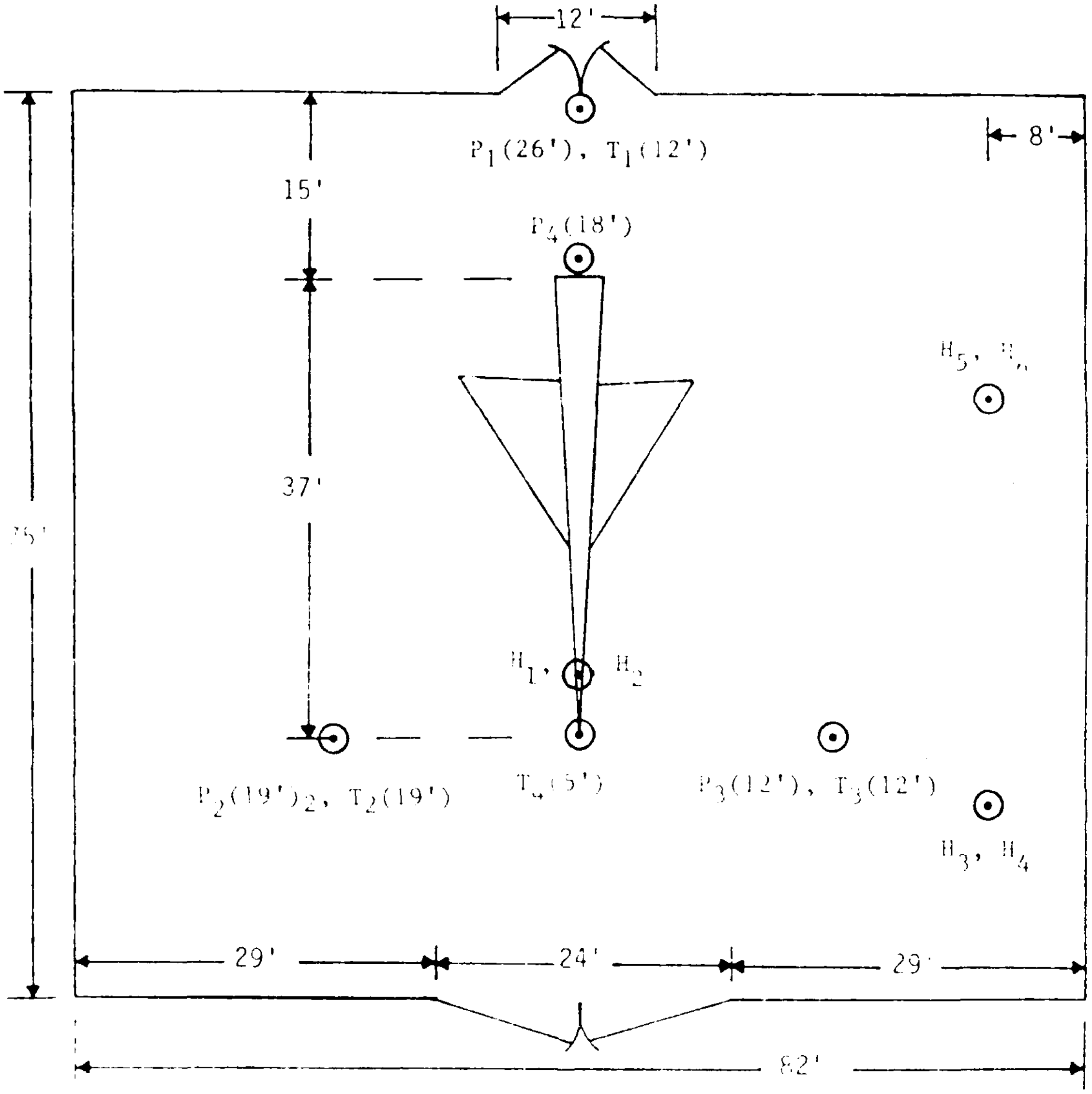
# APPENDIX B

# HARDENED AIRCRAFT SHELTER FIRE PROTECTION SYSTEM TEST RESULTS

Three fire protection systems from three manufacturers were tested at the Air Force Engineering and Services Center test site at Tyndall AFB, Panama City, Florida. The three system tests were designated Series A, Series B, and Series C. The test results and data are found in Sections I, II, and III of this appendix.

Instrumentation layouts for Series A, B and C are found in Figures B-1, and B-4 and B-19, respectively. The remaining Figures (through B-23) are time-temperature profiles of the individual tests.

NOTE: The material in this Appendix is published in its original format, with no substantial text editing or changes.




Notes: (1) T = thermocouple, P = pressure gage, and H = Perco halon gas concentration probe inlet.

(2) Numbers in parentheses are elevations above floor.

(3) See halon concentration tables for GC elevations.

Figure B-1. Instrumentation Series A, Tests 1 and 2.

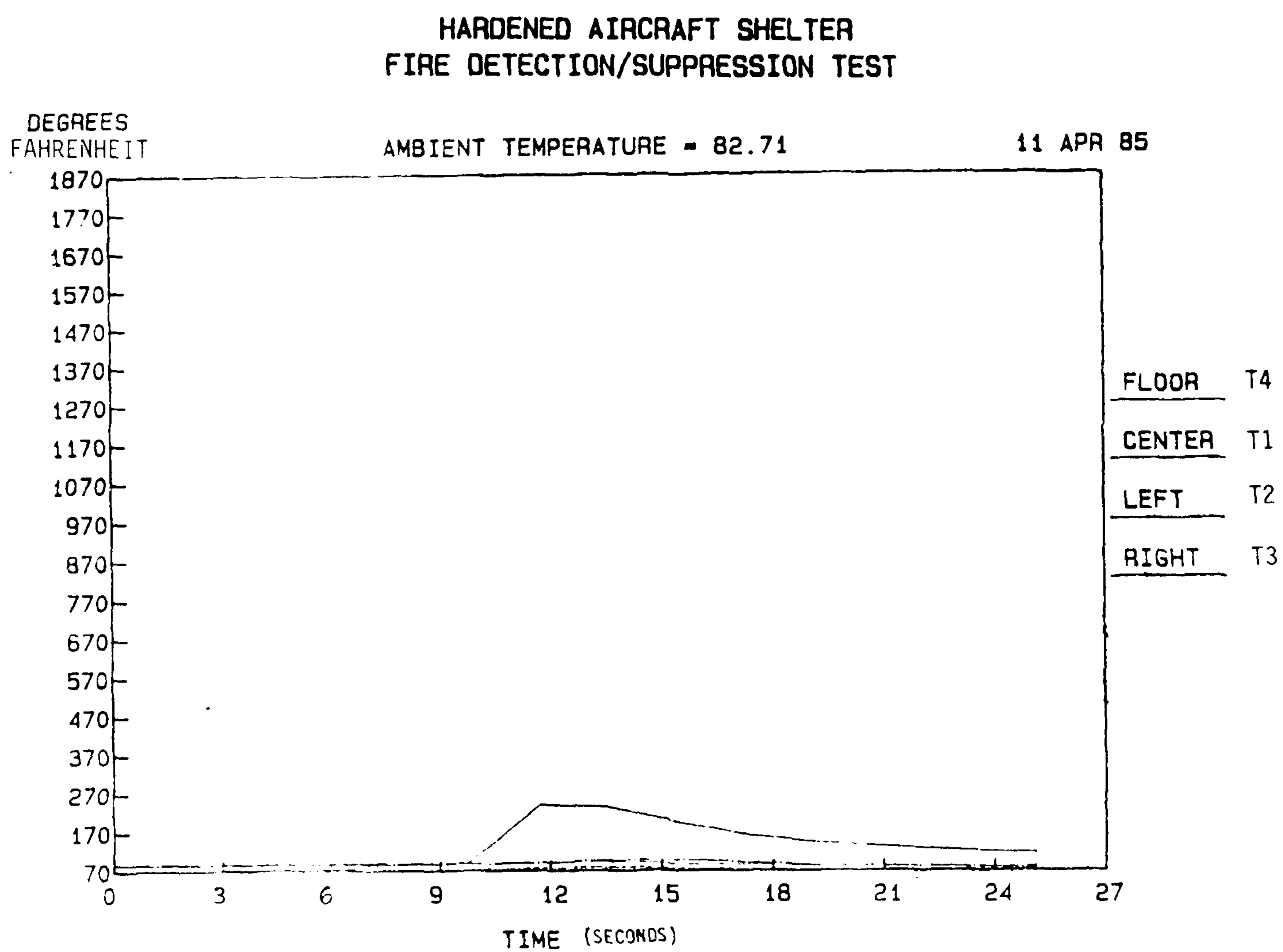



Figure 3-2. Series A, Test 1; T1, T2, T3, T4.

HARDENED AIRCRAFT SHELTER
FIRE DETECTION/SUPPRESSION TEST

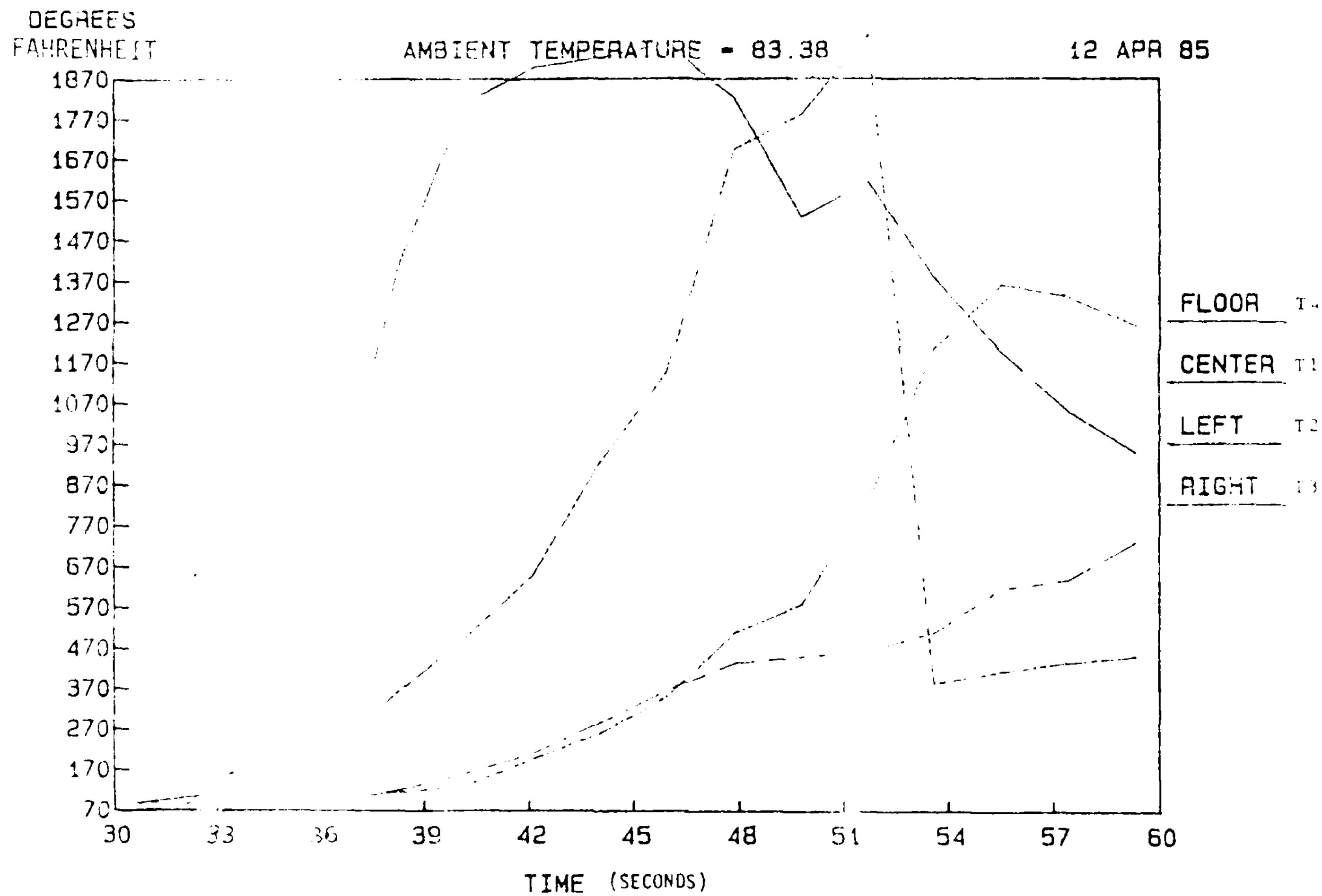
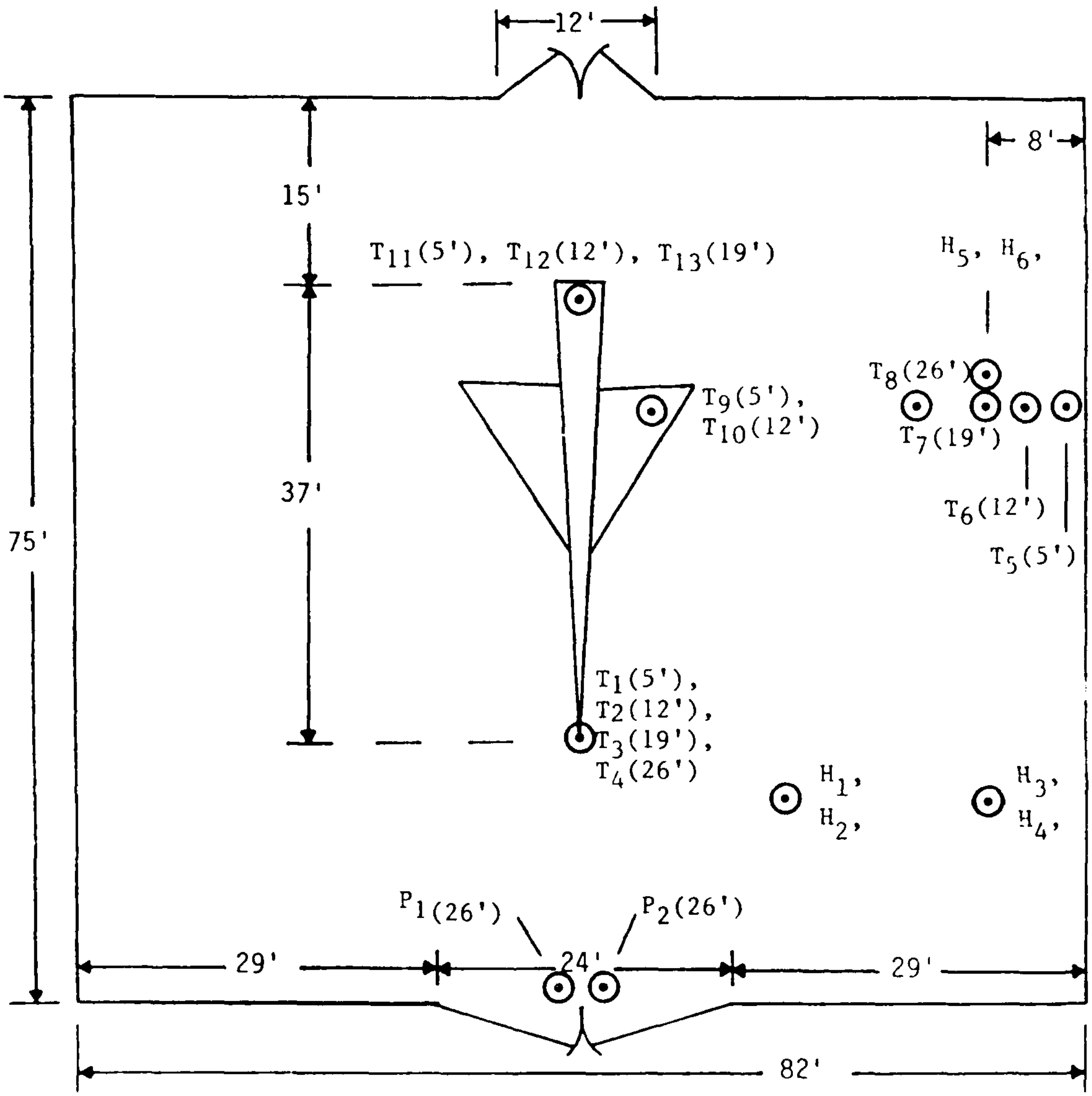



Figure B- . Series A, Test 2; T1, T2, T3, T4.




Notes: (1) T = thermocouple, P = pressure gage, and H = Perco halon gas concentration probe inlet.

(2) Numbers in parentheses are elevations above floor.

(3) See halon concentration tables for GC elevations.

Figure B-4. Instrumentation Series B, Tests 1 and 2.

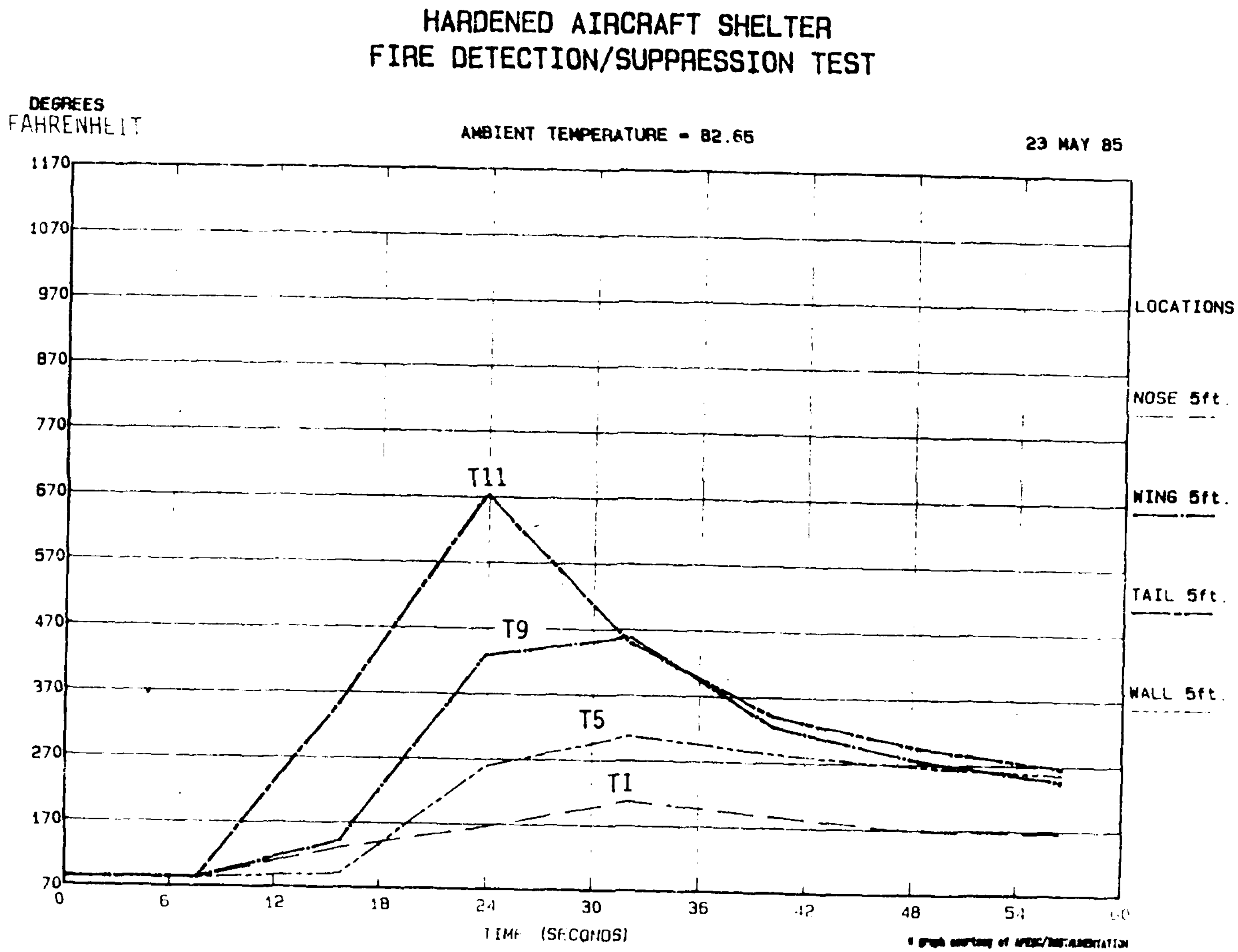



Figure B-5. Series B, Test 1; T1, T5, T9, T10.

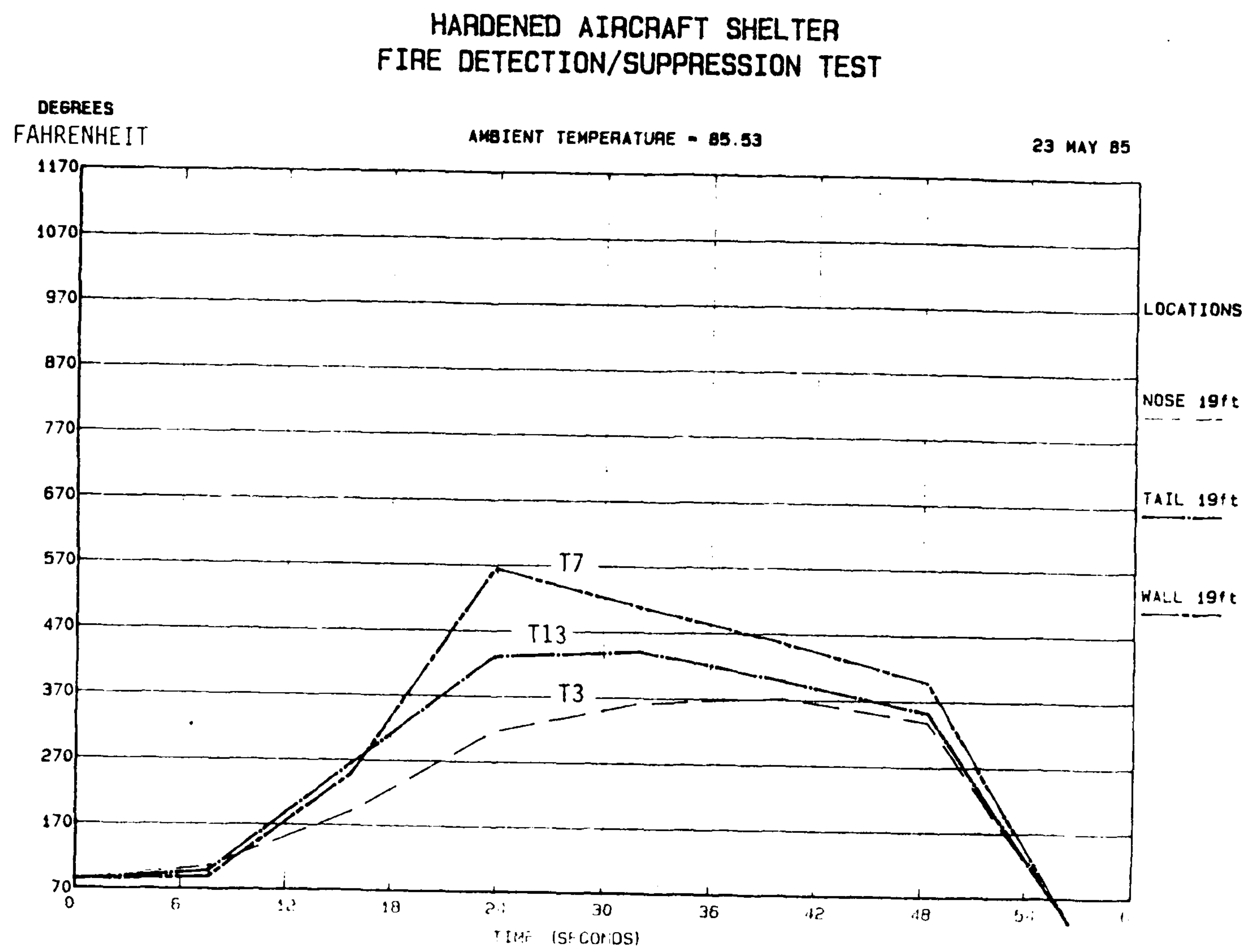



Figure B-6. Series B, Test 1; T3, T7, T13.

HARDENED AIRCRAFT SHELTER
FIRE DETECTION/SUPPRESSION TEST

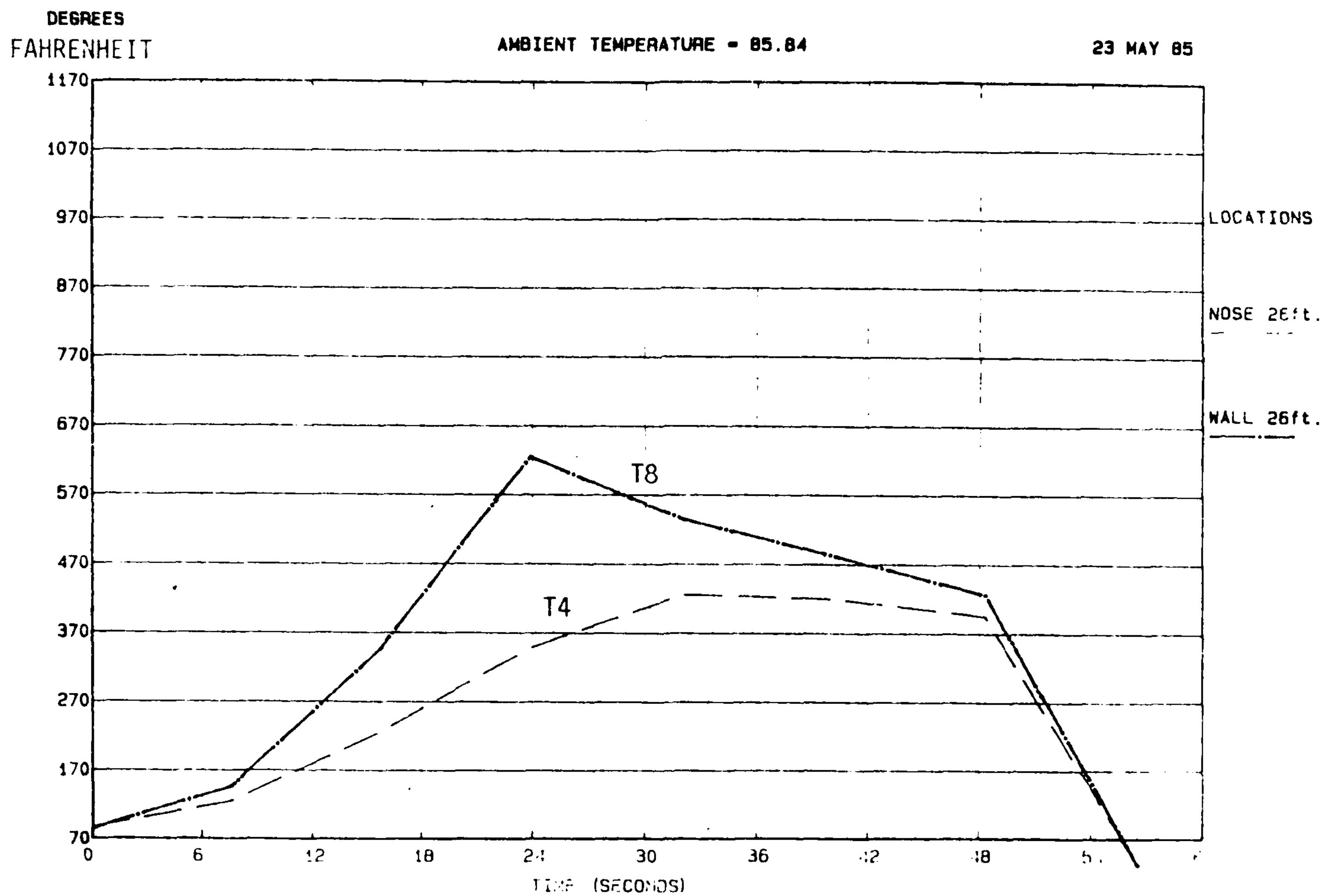



Figure B-7. Series B, Test 1; T4, T8.

HARDENED AIRCRAFT SHELTER
FIRE DETECTION/SUPPRESSION TEST

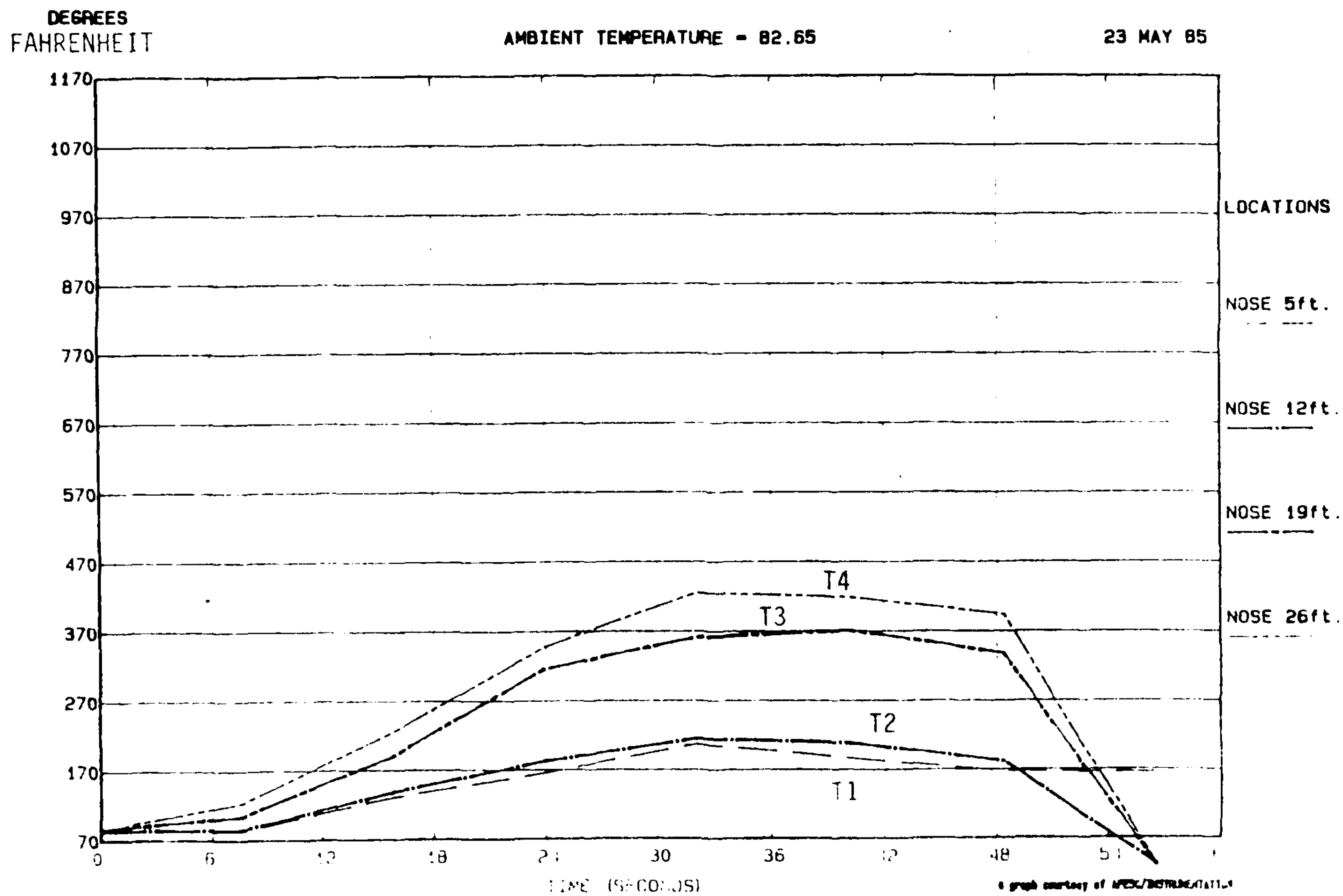



Figure B-8. Series B, Test 1; T1, T2, T3, T4.

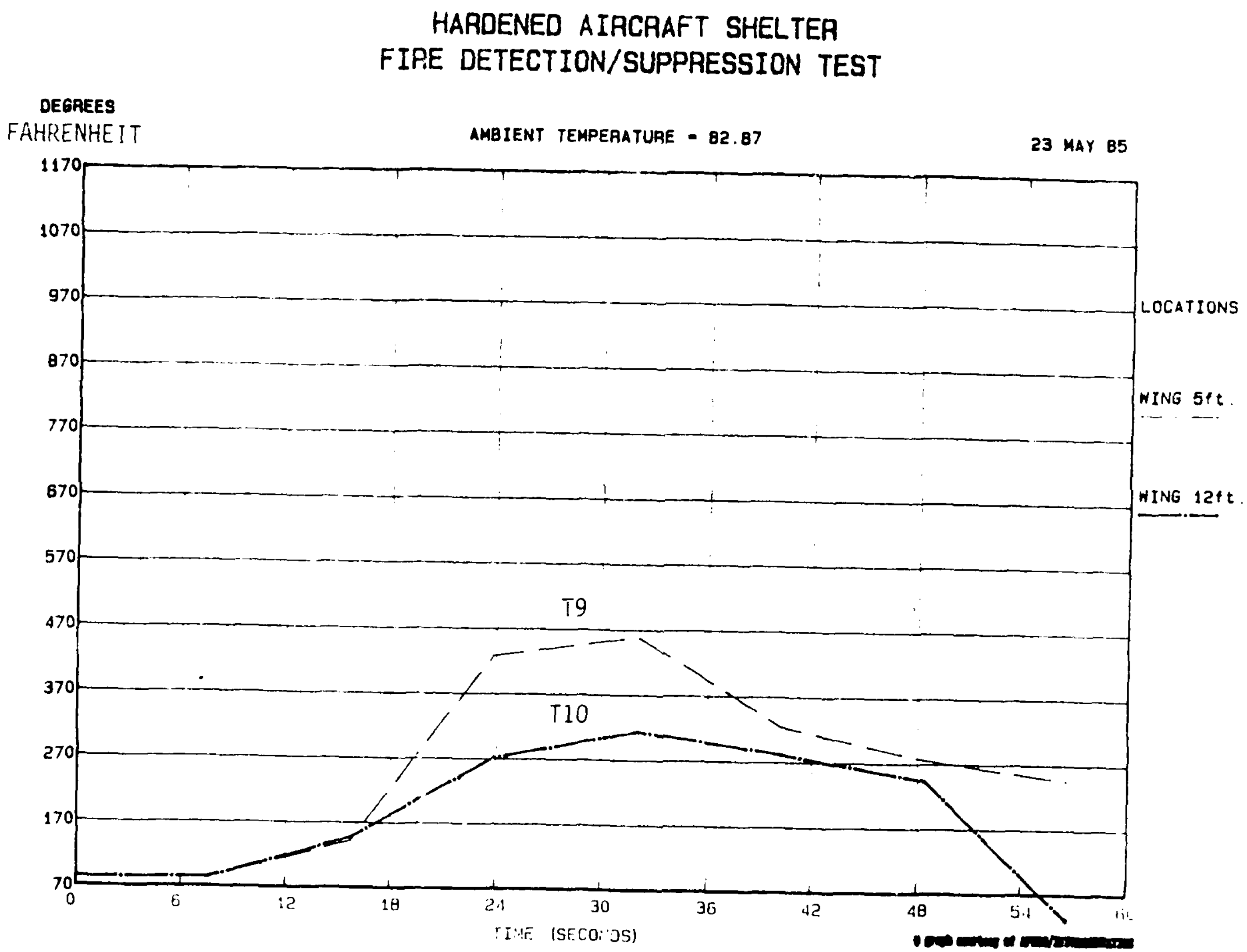



Figure B-9. Series B, Test 1; T9, T10.

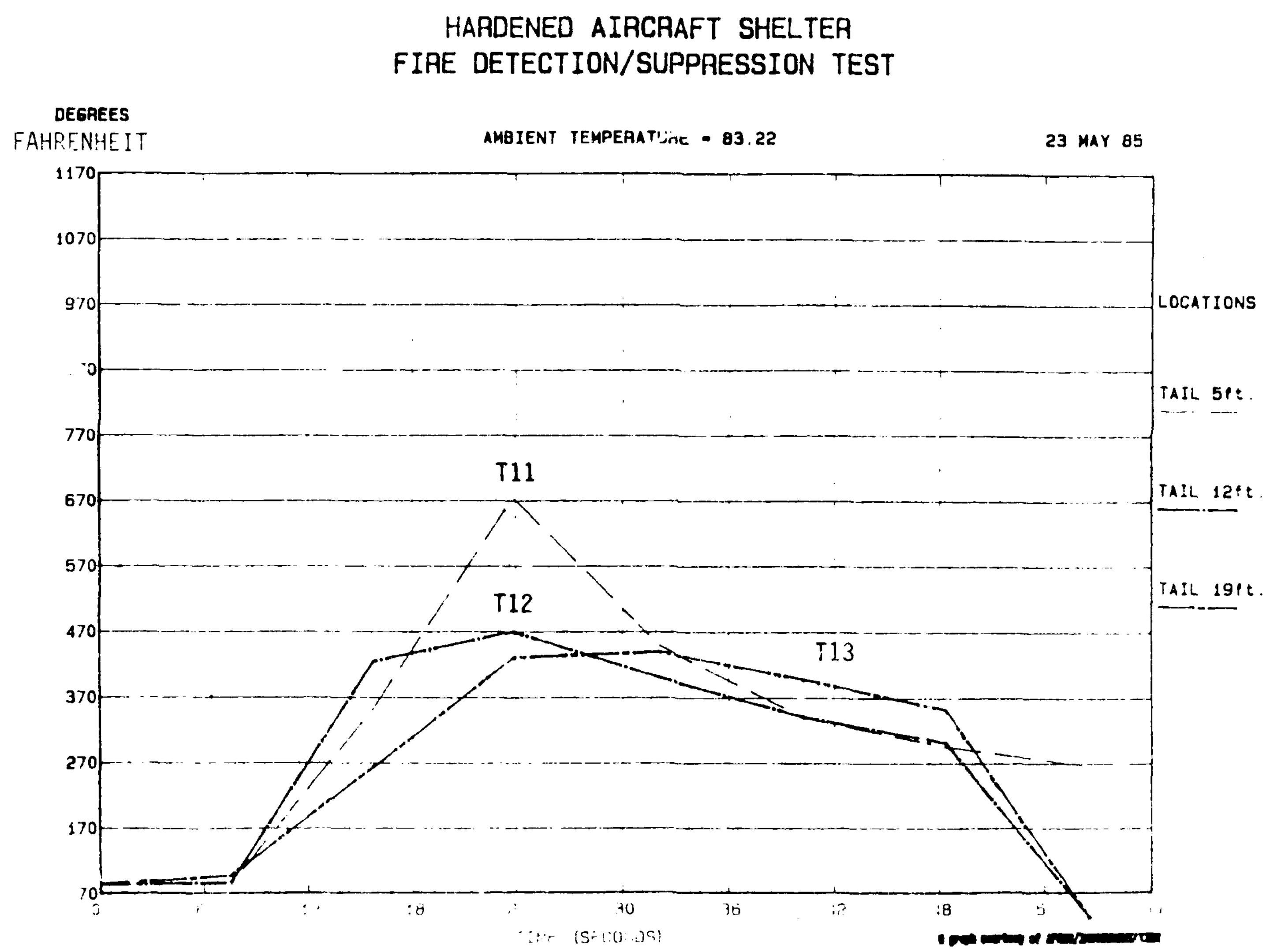



Figure B-10. Series B, Test 1; T11, T12, T13.

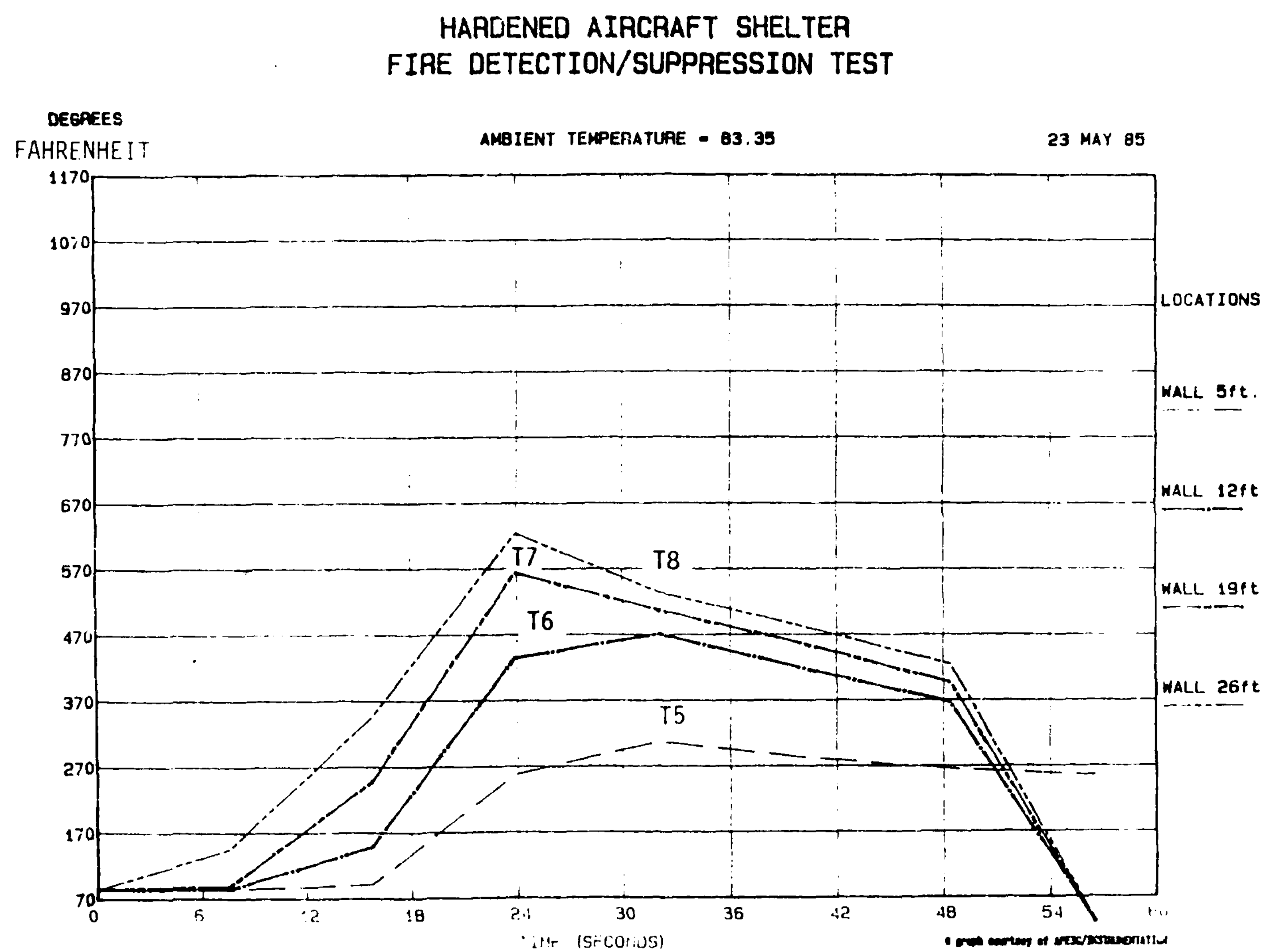



Figure B-11. Series B, Test 1; T5, T6, T7, T8.

## HARDENED AIRCRAFT SHELTER
## FIRE DETECTION/SUPPRESSION TEST

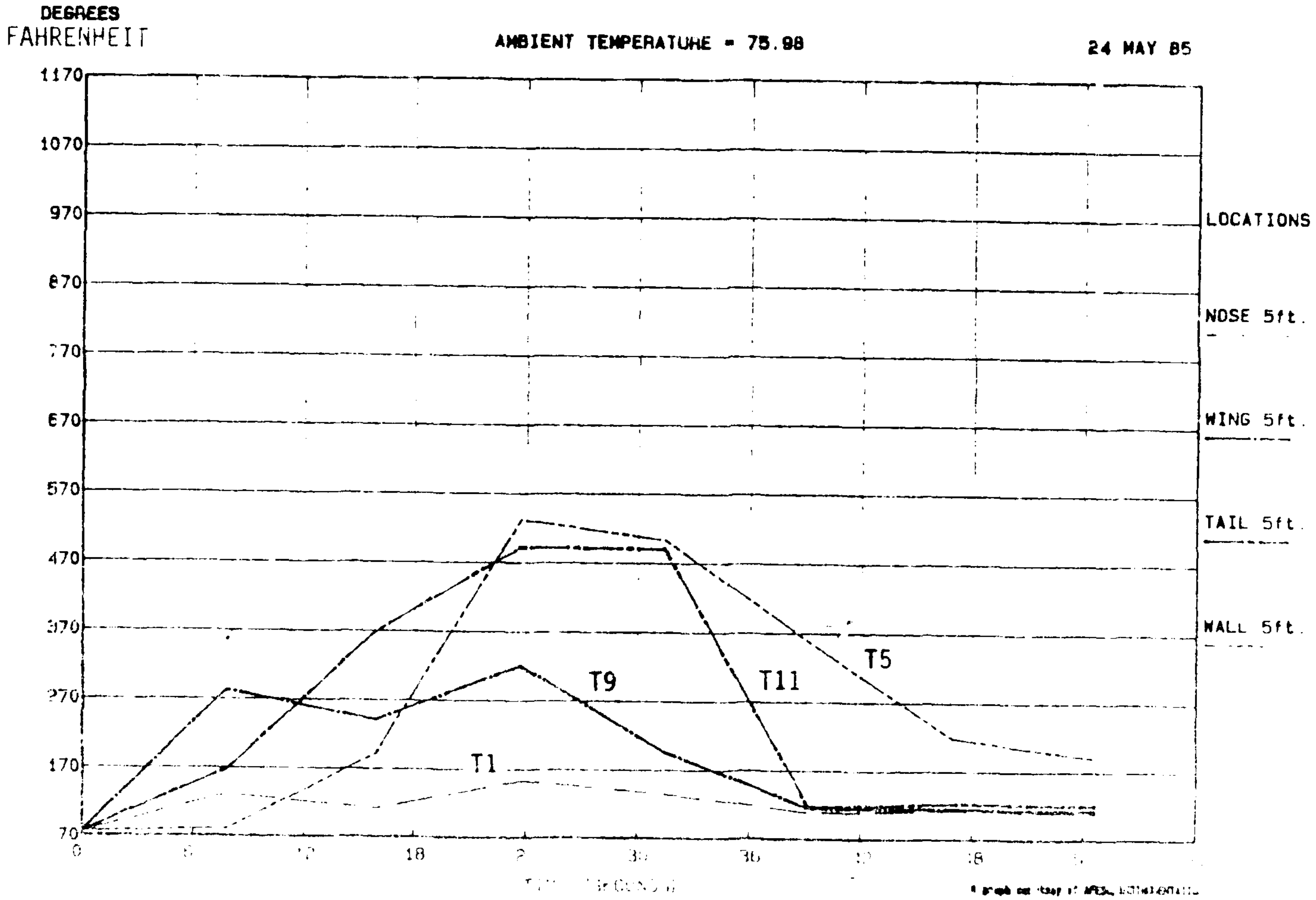



Figure B-12. Series B, Test 2; T1, T5, T9, T11.

HARDENED AIRCRAFT SHELTER
FIRE DETECTION/SUPPRESSION TEST

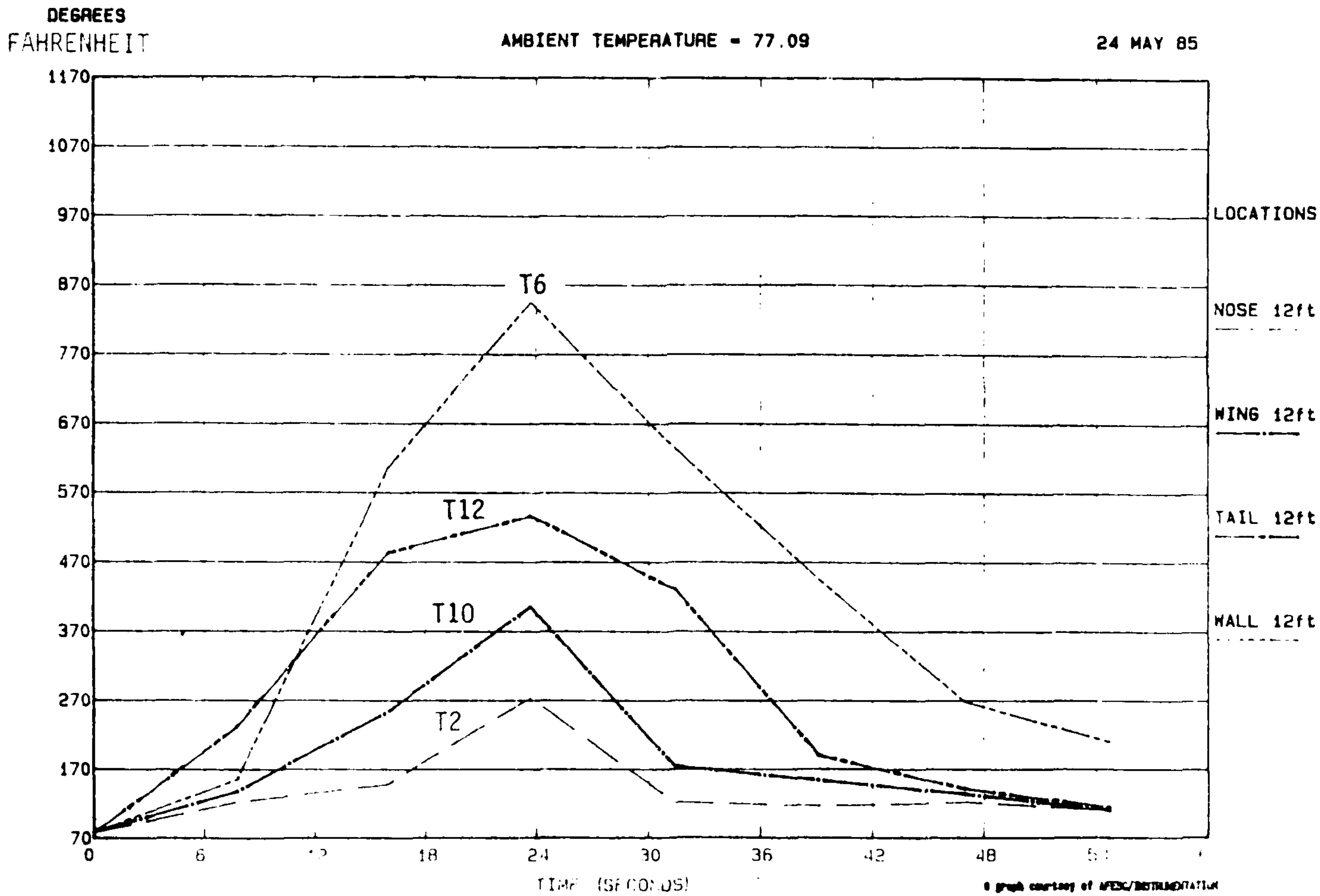
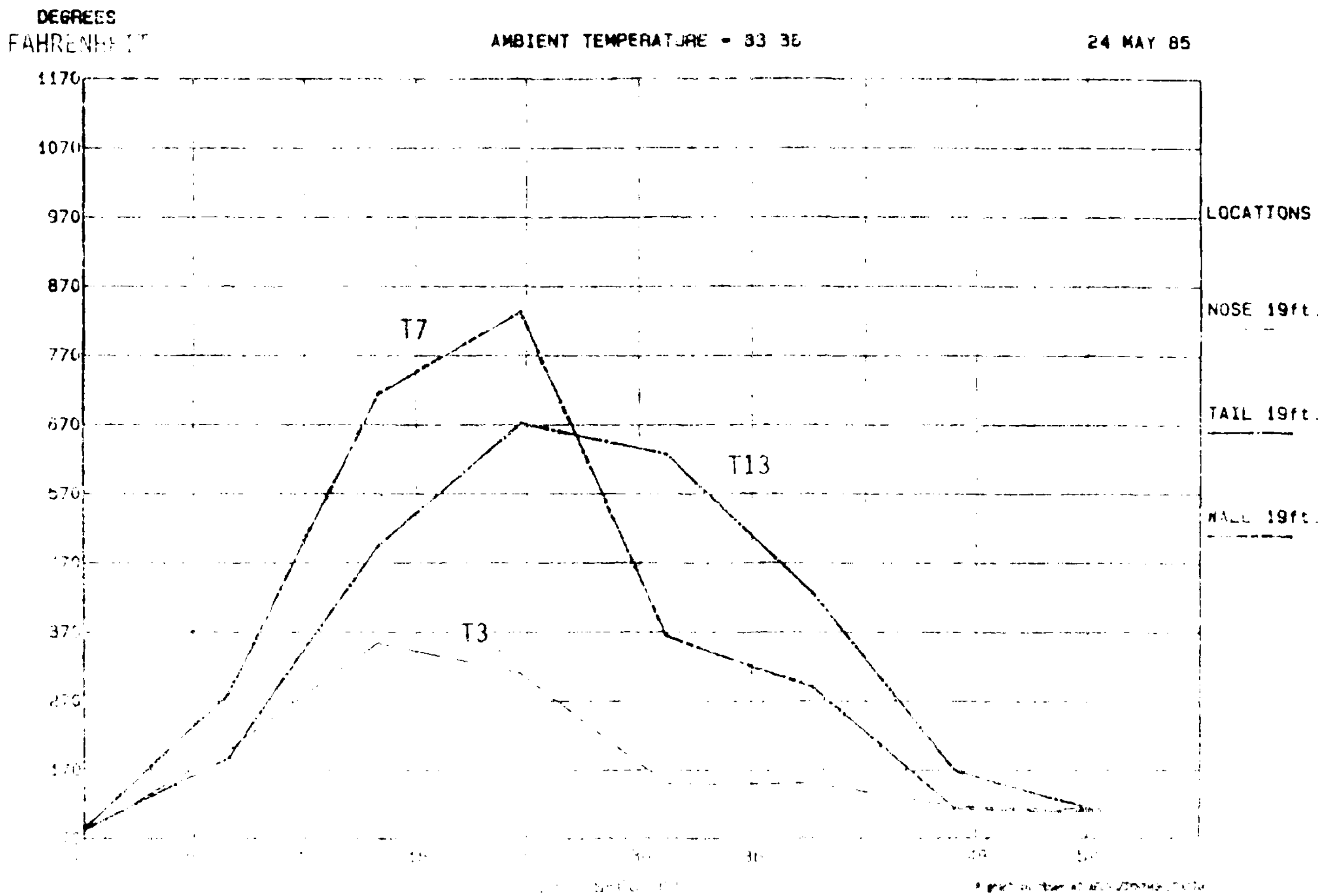



Figure B-13. Series B, Test 2; T2, T6, T10, T12.

# HARDENED AIRCRAFT SHELTER
# FIRE DETECTION/SUPPRESSION TEST




[illegible] Test 2; T3, T7, [illegible]

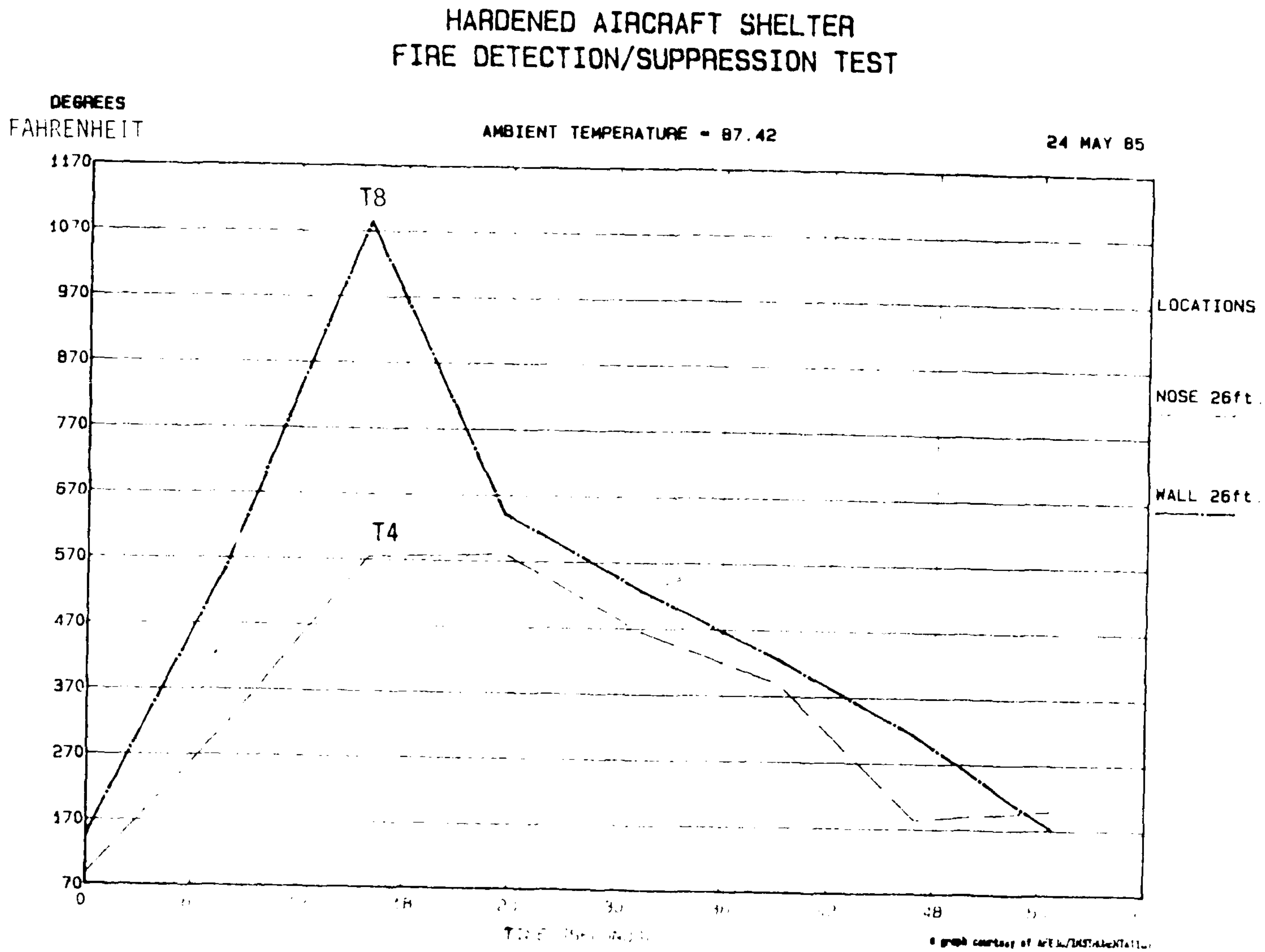
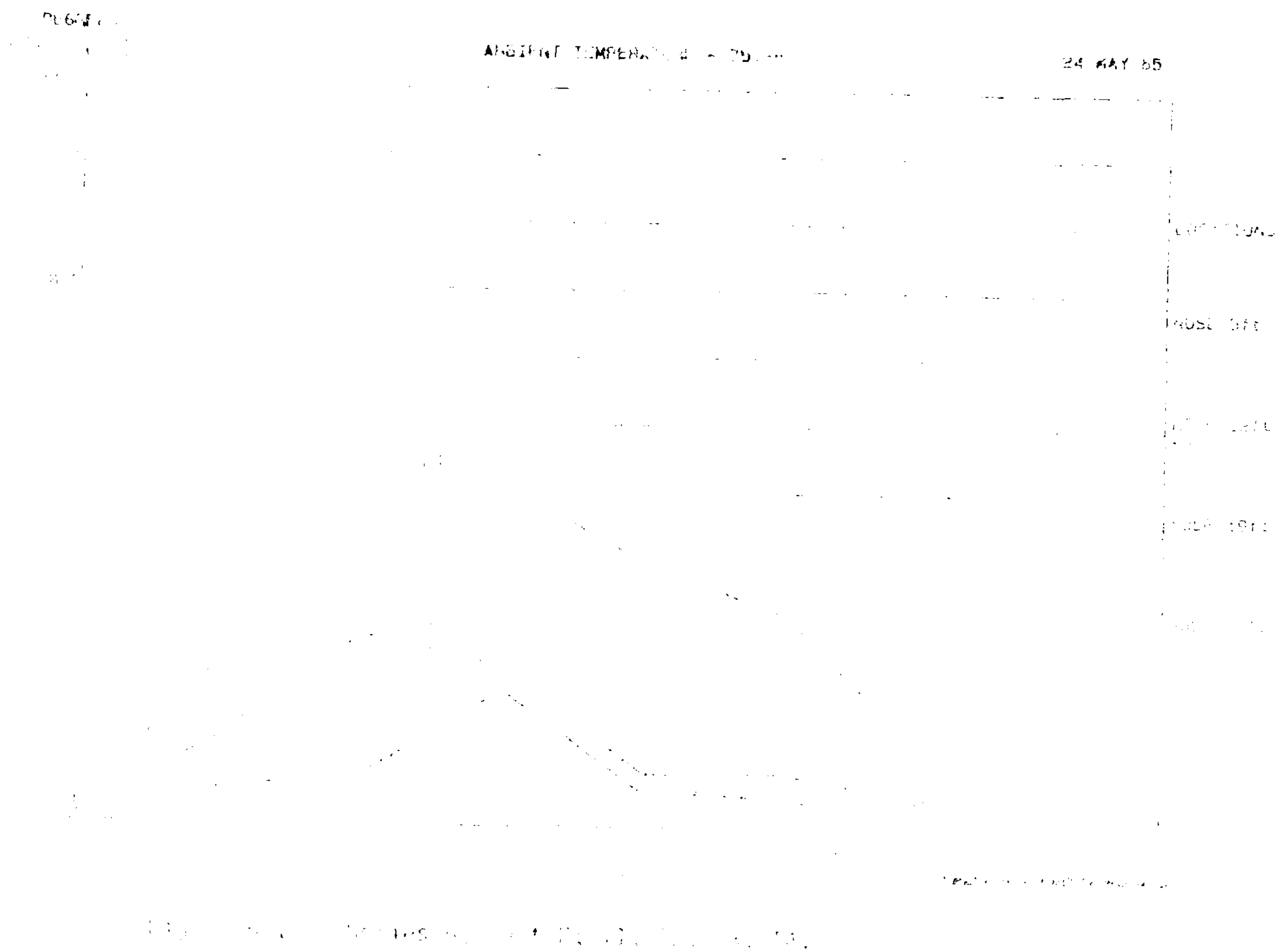



Figure B-15. Series B, Test 2; T4, T8.

HARDENED AIRCRAFT SHELTER
[illegible] DE[illegible]TION/SUPPRESSION TEST

AMBIENT TEMPERA[illegible] = 75 [illegible]

24 MAY 85



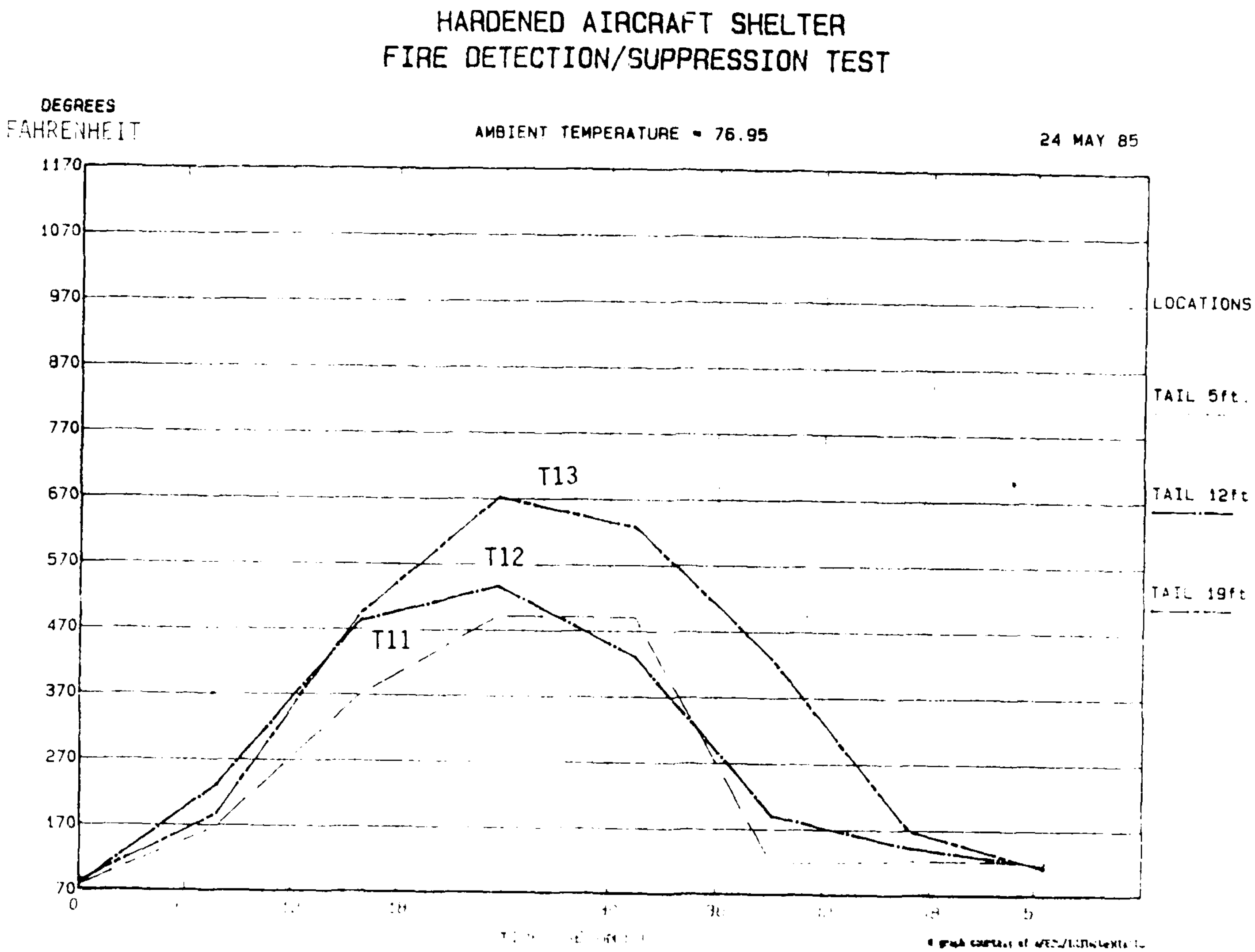
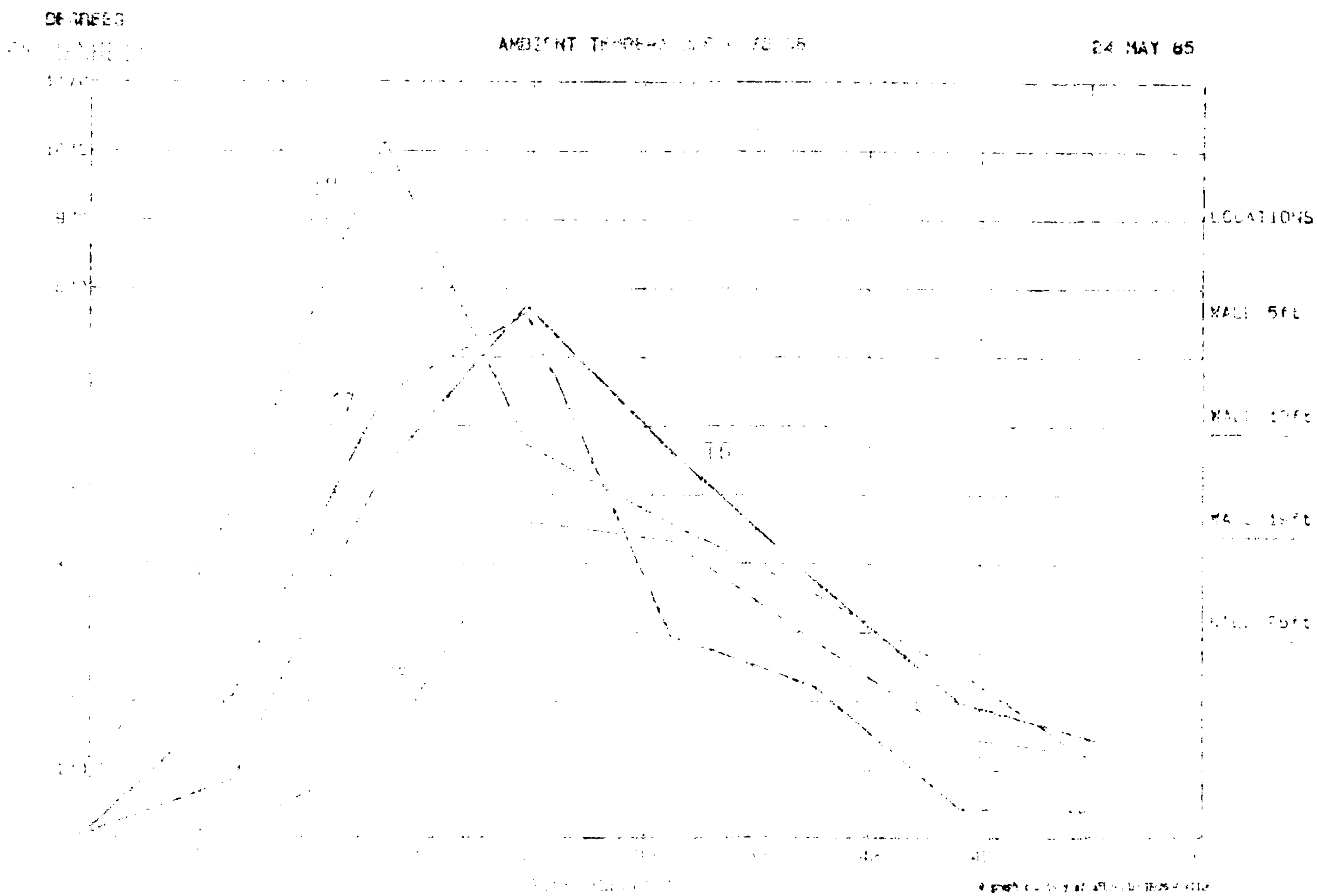
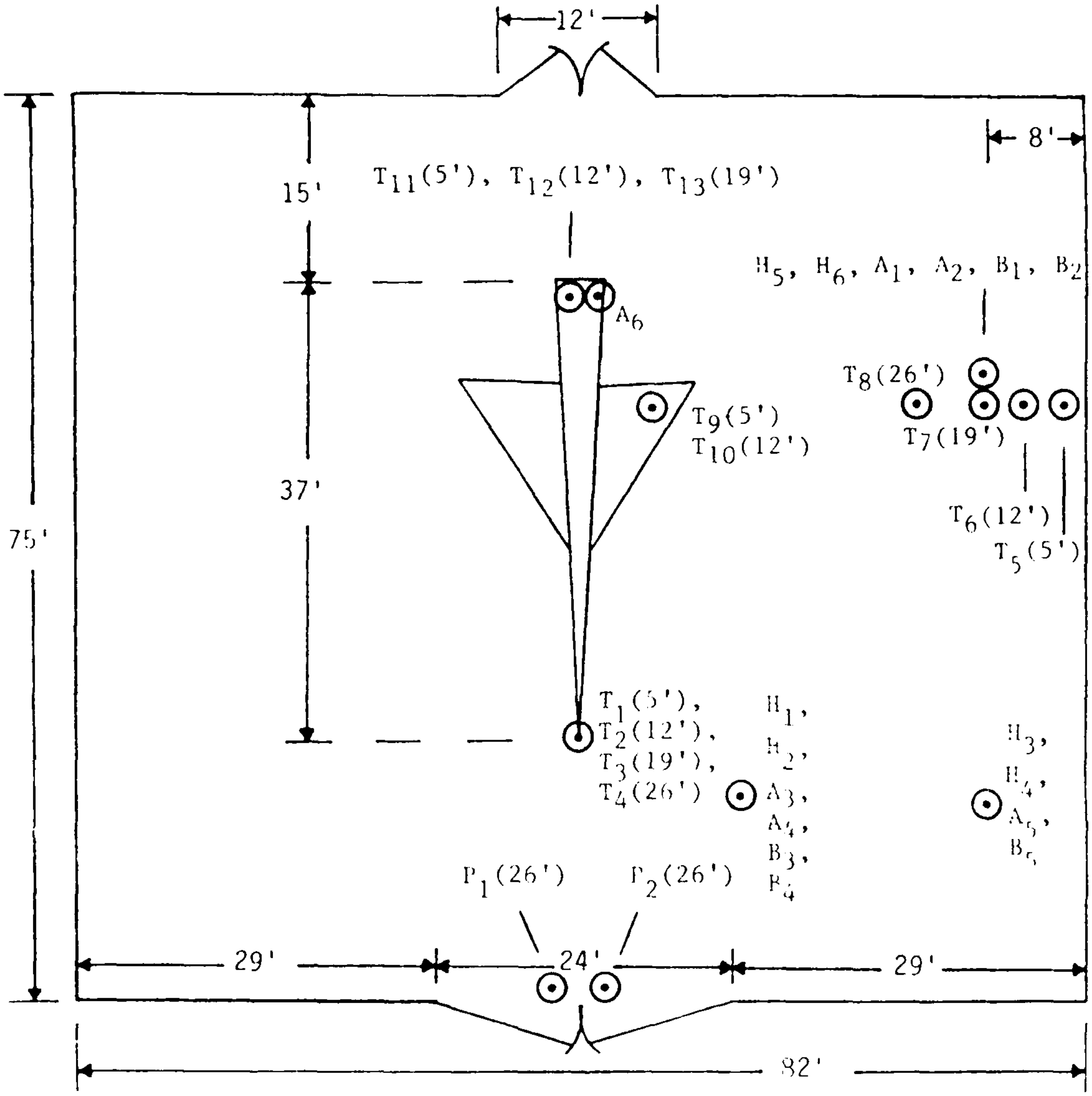



Figure B-17. Series B, Test 2; T11, T12, T13.

HARDENED AIRCRAFT SHELTER
FIRE DETECTION/SUPPRESSION TEST






Notes: (1) T = thermocouple, P = pressure gage, and H = Perco halon gas concentration probe inlet.

(2) Numbers in parentheses are elevations above floor.

(3) See halon concentration tables for GC elevations.

(4) A = 20-pound propane tank grab samples and B = 500 cc cylinder grab samples.

Figure B-19. Instrumentation Series C, Tests 1 and 2.

HARDENED AIRCRAFT SHELTER
FIRE DETECTION/SUPPRESSION TEST

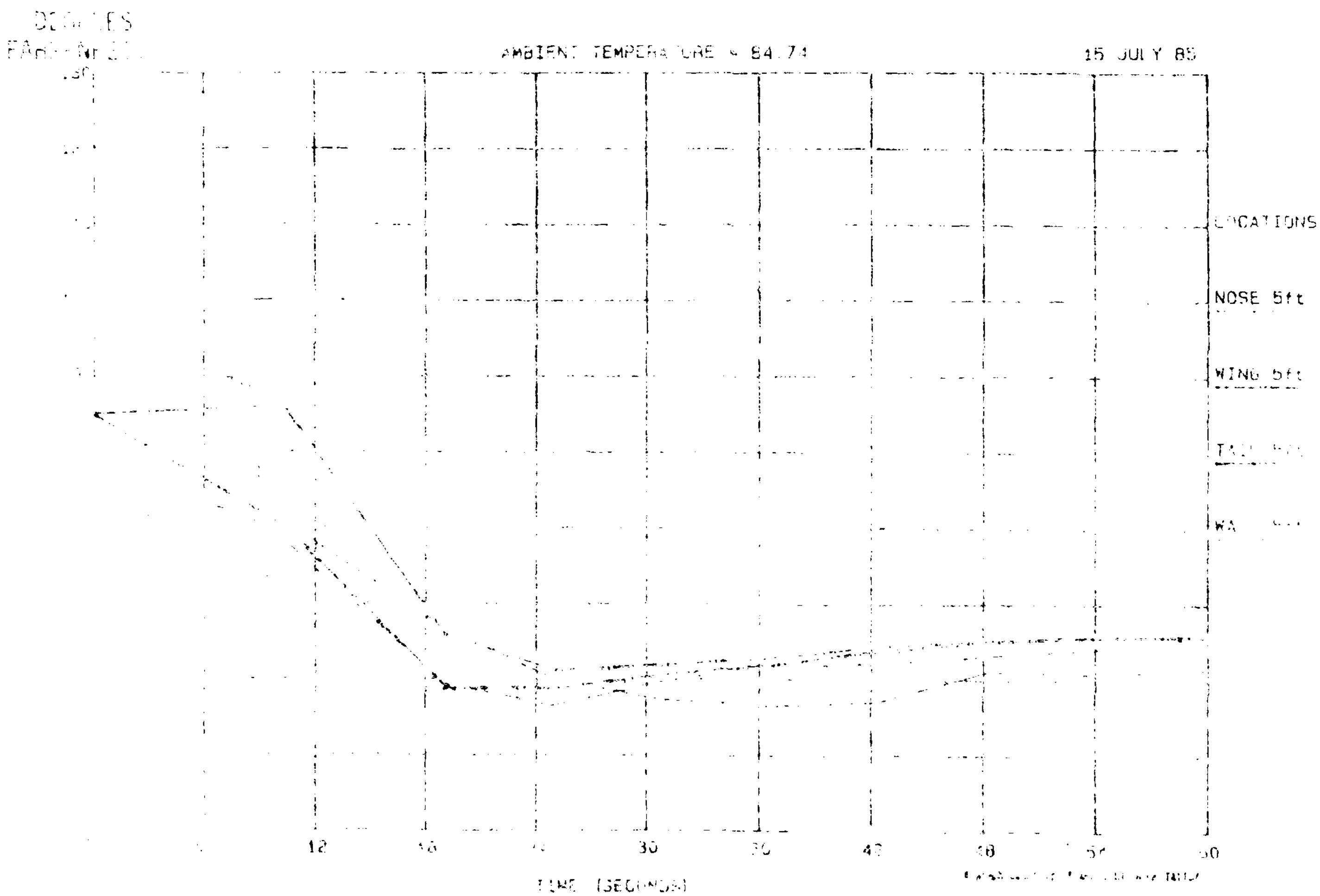



Figure 5-20  Series C, Test 2; T1, T5, T9, T11.

HARDENED AIRCRAFT SHELTER
FIRE DETECTION/SUPPRESSION TEST

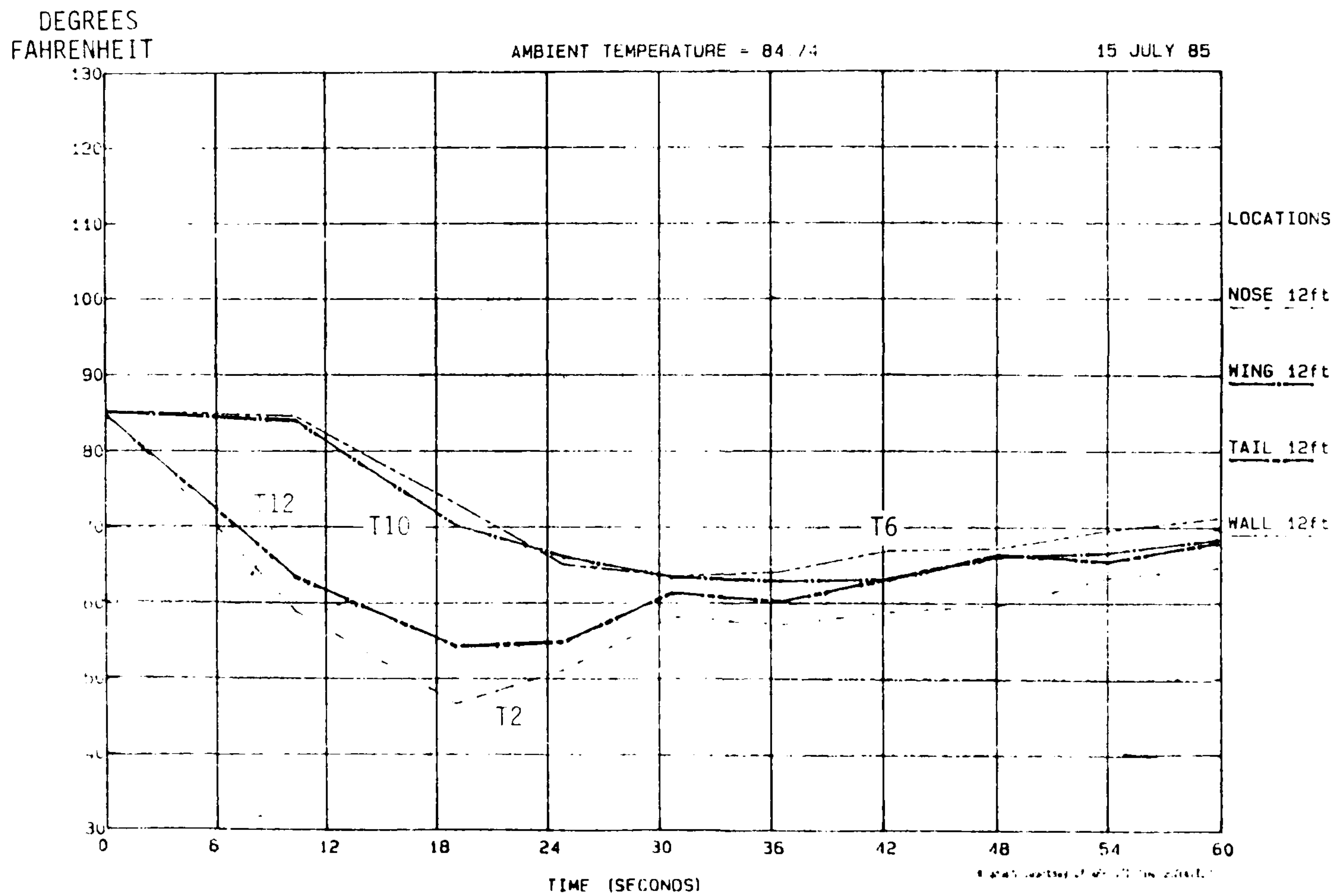



Figure B-21. Series C, Test 2; T2, T6, T10, T12.

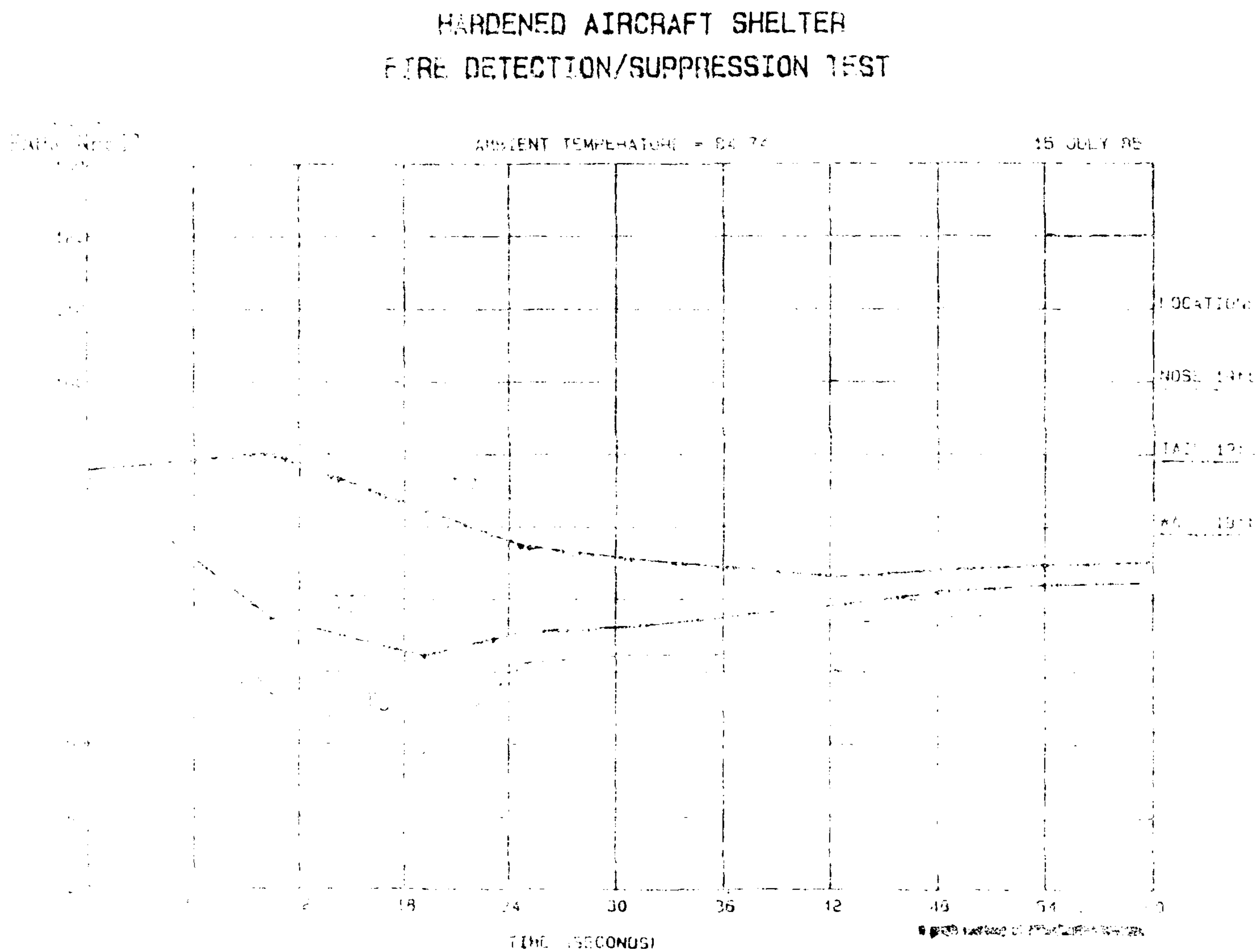



Figure B-22. Series C, Test 2: T3, T7, T13.

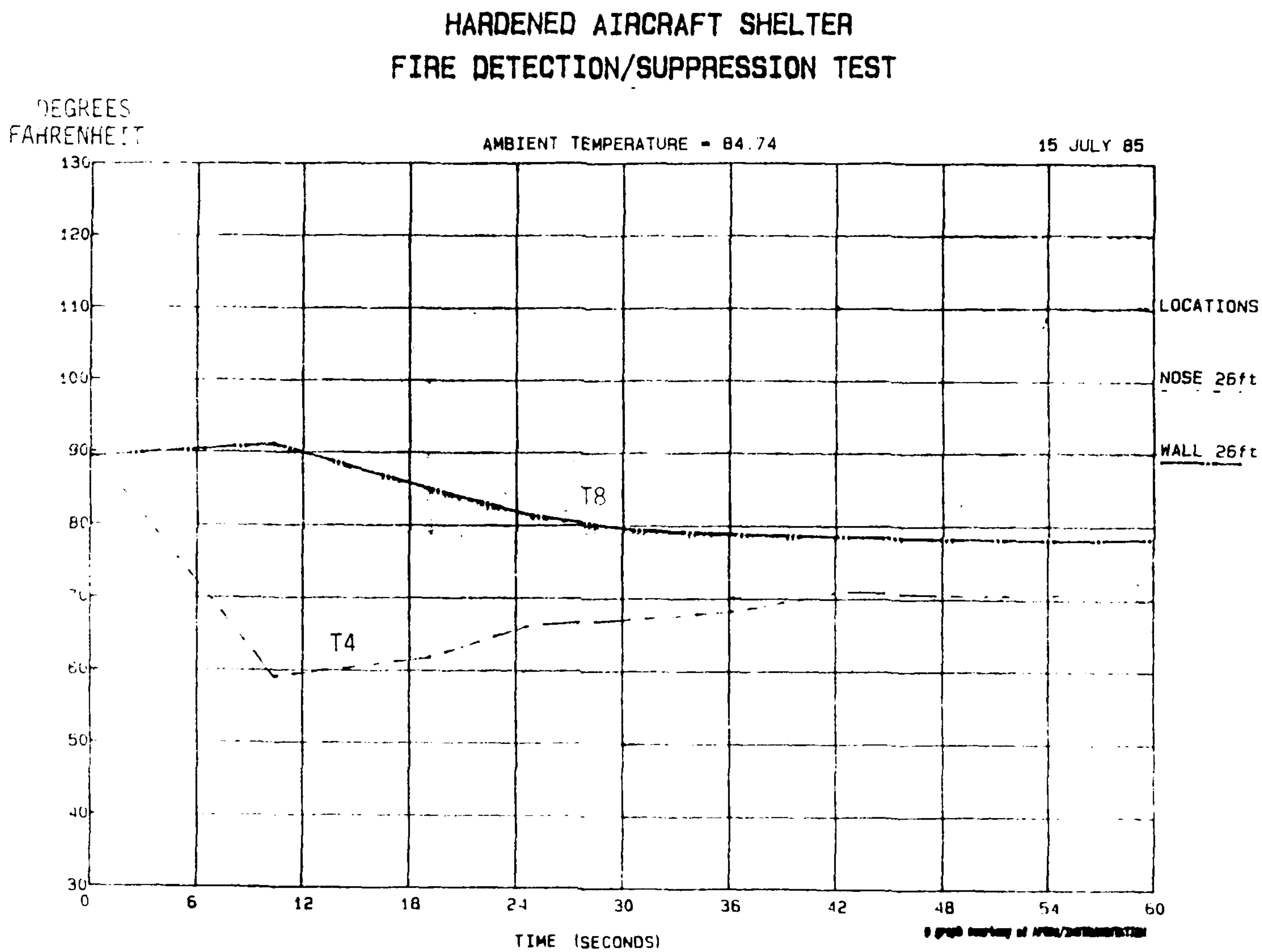



Figure B-23. Series C, Test 2; T4, T8.

# APPENDIX C

## HALON CONCENTRATION DATA

NOTE: The material in this Appendix is published in its original format, with no substantial text editing or changes.

TABLE C-1. UNCORRECTED HALON CONCENTRATION DATA, PROBE H1, TEST 1, SERIES A.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 5 | 0.10 | 205 | 1.45 | 405 | 0.35 |
| 10 | 0.70 | 210 | 1.45 | 410 | 0.35 |
| 15 | 2.05 | 215 | 1.35 | 415 | 0.35 |
| 20 | 3.15 | 220 | 1.20 | 420 | 0.30 |
| 25 | 3.45 | 225 | 1.05 | 425 | 0.30 |
| 30 | 3.65 | 230 | 1.15 | 430 | 0.30 |
| 35 | 3.90 | 235 | 1.15 | 435 | 0.35 |
| 40 | 4.20 | 240 | 1.15 | 440 | 0.35 |
| 45 | 4.40 | 245 | 1.10 | 445 | 0.35 |
| 50 | 4.60 | 250 | 1.00 | 450 | 0.20 |
| 55 | 4.70 | 255 | 0.90 | 455 | 0.20 |
| 60 | 4.75 | 260 | 0.90 | 460 | 0.20 |
| 65 | 4.75 | 265 | 1.00 | 465 | 0.20 |
| 70 | 4.75 | 270 | 1.05 | 470 | 0.20 |
| 75 | 4.60 | 275 | 1.00 | 475 | 0.15 |
| 80 | 4.55 | 280 | 0.85 | 480 | 0.15 |
| 85 | 4.45 | 285 | 0.80 | 485 | 0.15 |
| 90 | 4.30 | 290 | 0.75 | 490 | 0.20 |
| 95 | 4.25 | 295 | 0.75 | 495 | 0.20 |
| 100 | 4.25 | 300 | 0.75 | 500 | 0.20 |
| 105 | 4.20 | 305 | 0.70 | 505 | 0.20 |
| 110 | 3.85 | 310 | 0.65 | 510 | 0.20 |
| 115 | 3.35 | 315 | 0.60 | 515 | 0.20 |
| 120 | 3.15 | 320 | 0.55 | 520 | 0.20 |
| 125 | 3.25 | 325 | 0.55 | 525 | 0.20 |
| 130 | 3.15 | 330 | 0.50 | 530 | 0.10 |
| 135 | 2.75 | 335 | 0.50 | 535 | 0.05 |
| 140 | 2.50 | 340 | 0.55 | 540 | 0.05 |
| 145 | 2.45 | 345 | 0.55 | 545 | 0.05 |
| 150 | 2.60 | 350 | 0.55 | 550 | 0.10 |
| 155 | 2.50 | 355 | 0.50 | 555 | 0.80 |
| 160 | 2.40 | 360 | 0.50 | 560 | 0.60 |
| 165 | 2.15 | 365 | 0.50 | 565 | 0.45 |
| 170 | 2.00 | 370 | 0.50 | 570 | 0.25 |
| 175 | 2.00 | 375 | 0.50 | 575 | 0.15 |
| 180 | 1.85 | 380 | 0.45 | 580 | 0.15 |
| 185 | 1.65 | 385 | 0.45 | 585 | 0.10 |
| 190 | 1.55 | 390 | 0.40 | 590 | 0.05 |
| 195 | 1.50 | 395 | 0.40 | 595 | 0.05 |
| 200 | 1.55 | 400 | 0.35 | 600 | 0.05 |

TABLE C-2. UNCORRECTED HALON CONCENTRATION DATA, PROBE H2, TEST 1, SERIES A.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 5 | 0.60 | 210 | 3.60 | 415 | [illegible] |
| 10 | 2.25 | 215 | 3.40 | 420 | 0.70 |
| 15 | 3.75 | 220 | 3.20 | 425 | 0.60 |
| 20 | 4.20 | 225 | 3.20 | [illegible] | [illegible] |
| 25 | 4.30 | 230 | 3.20 | [illegible] | [illegible] |
| 30 | 4.45 | 235 | 2.95 | [illegible] | [illegible] |
| 35 | 4.50 | 240 | 2.55 | [illegible] | [illegible] |
| 40 | 4.65 | 245 | 2.20 | [illegible] | [illegible] |
| 45 | 4.85 | 250 | [illegible] | [illegible] | [illegible] |
| 50 | 4.95 | 255 | [illegible] | 460 | [illegible] |
| 55 | 5.00 | 260 | 2.55 | [illegible] | [illegible] |
| 60 | 5.10 | 265 | 2.50 | 470 | [illegible] |
| 65 | 5.15 | 270 | 2.40 | 475 | 0.40 |
| 70 | 5.15 | 275 | 2.55 | 480 | 0.50 |
| 75 | 5.15 | 280 | 2.65 | 485 | 0.50 |
| 80 | 5.15 | 285 | 2.75 | 490 | 0.45 |
| 85 | 5.15 | 290 | 2.40 | 495 | 0.45 |
| 90 | 5.15 | 295 | 2.05 | 500 | 0.40 |
| 95 | 5.05 | 300 | 1.80 | 505 | 0.40 |
| 100 | 5.05 | 305 | 1.70 | [illegible] | [illegible] |
| 105 | 5.05 | 310 | 1.70 | 515 | 0.40 |
| 110 | 4.90 | 315 | 1.70 | 520 | 0.40 |
| 115 | 4.85 | 320 | 1.75 | 525 | 0.50 |
| 120 | 4.95 | 325 | 1.75 | [illegible] | [illegible] |
| 125 | 5.00 | 330 | 1.70 | [illegible] | [illegible] |
| 130 | 5.00 | 335 | 1.70 | [illegible] | [illegible] |
| 135 | 4.95 | 340 | 1.80 | [illegible] | [illegible] |
| 140 | 4.90 | 345 | 2.10 | [illegible] | [illegible] |
| 145 | 4.90 | 350 | 2.00 | 555 | 0.30 |
| 150 | 4.90 | 355 | [illegible] | [illegible] | [illegible] |
| 155 | 4.90 | 360 | [illegible] | [illegible] | 0.65 |
| 160 | 4.85 | 365 | [illegible] | [illegible] | 0.50 |
| 165 | 4.85 | 370 | [illegible] | [illegible] | 0.35 |
| 170 | 4.90 | [illegible] | [illegible] | [illegible] | [illegible] |
| 175 | 4.65 | 380 | [illegible] | [illegible] | [illegible] |
| 180 | 4.25 | [illegible] | [illegible] | [illegible] | [illegible] |
| 185 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 190 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 195 | 3.80 | 400 | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | 405 | [illegible] | | |
| [illegible] | [illegible] | 410 | [illegible] | | |

TABLE C-3. UNCORRECTED HALON CONCENTRATION DATA, PROBE H3, TEST 1, SERIES A.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 5 | 0.40 | 200 | 1.45 | 395 | 0.50 |
| 10 | 1.90 | 205 | 1.40 | 400 | 0.50 |
| 15 | 2.95 | 210 | 1.35 | 405 | 0.50 |
| 20 | 3.50 | 215 | 1.30 | 410 | 0.50 |
| 25 | 3.75 | 220 | 1.30 | 415 | 0.45 |
| 30 | 4.15 | 225 | 1.25 | 420 | 0.45 |
| 35 | 4.55 | 230 | 1.10 | 425 | 0.40 |
| 40 | 4.85 | 235 | 1.00 | 430 | 0.40 |
| 45 | 4.95 | 240 | 1.05 | 435 | 0.40 |
| 50 | 4.95 | 245 | 1.10 | 440 | 0.40 |
| 55 | 4.90 | 250 | 1.15 | 445 | 0.40 |
| 60 | 4.90 | 255 | 1.20 | 450 | 0.45 |
| 65 | 4.90 | 260 | 1.10 | 455 | 0.45 |
| 70 | 4.85 | 265 | 1.05 | 460 | 0.45 |
| 75 | 4.50 | 270 | 1.00 | 465 | 0.45 |
| 80 | 4.25 | 275 | 0.95 | 470 | 0.40 |
| 85 | 4.15 | 280 | 0.90 | 475 | 0.35 |
| 90 | 4.25 | 285 | 0.85 | 480 | 0.35 |
| 95 | 4.35 | 290 | 0.85 | 485 | 0.35 |
| 100 | 4.35 | 295 | 0.90 | 490 | 0.30 |
| 105 | 4.35 | 300 | 0.85 | 495 | 0.35 |
| 110 | 4.25 | 305 | 0.80 | 500 | 0.35 |
| 115 | 3.70 | 310 | 0.80 | 505 | 0.35 |
| 120 | 3.10 | 315 | 0.80 | 510 | 0.35 |
| 125 | 2.80 | 320 | 0.75 | 515 | 0.35 |
| 130 | 2.65 | 325 | 0.75 | 520 | 0.35 |
| 135 | 2.50 | 330 | 0.75 | 525 | 0.35 |
| 140 | 2.80 | 335 | 0.70 | 530 | 0.30 |
| 145 | 2.75 | 340 | 0.70 | 535 | 0.30 |
| 150 | 2.45 | 345 | 0.70 | 540 | 0.30 |
| 155 | 2.25 | 350 | 0.70 | 545 | 0.30 |
| 160 | 2.10 | 355 | 0.70 | 550 | 0.30 |
| 165 | 1.95 | 360 | 0.65 | 555 | 0.05 |
| 170 | 1.70 | 365 | 0.65 | 560 | 0.10 |
| 175 | 1.50 | 370 | 0.65 | 565 | 0.05 |
| 180 | 1.50 | 375 | 0.60 | 570 | 0.05 |
| 185 | 1.65 | 380 | 0.60 | 575 | 0.05 |
| 190 | 1.65 | 385 | 0.55 | 580 | 0.05 |
| 195 | 1.60 | 390 | 0.50 | | |

TABLE C-4. UNCORRECTED HALON CONCENTRATION DATA, PROBE H4, [illegible], SERIES [illegible]

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 5 | 1.00 | 210 | 4.50 | 415 | 1.40 |
| 10 | 2.45 | 215 | 4.05 | 420 | 1.35 |
| 15 | 3.20 | 220 | 3.85 | 425 | 1.25 |
| 20 | 3.70 | 225 | 3.85 | 430 | [illegible] |
| 25 | 4.05 | 230 | 3.75 | 435 | 1.00 |
| 30 | 4.40 | 235 | 3.40 | 440 | 1.05 |
| 35 | 4.75 | 240 | 3.20 | 445 | 1.20 |
| 40 | 5.15 | 245 | 3.30 | 450 | 1.40 |
| 45 | 5.30 | 250 | 3.30 | 455 | 1.25 |
| 50 | 5.35 | 255 | 2.80 | 460 | 1.10 |
| 55 | 5.30 | 260 | 1.90 | 465 | 1.05 |
| 60 | 5.30 | 265 | 1.2[illegible] | 470 | 0.95 |
| 65 | 5.35 | 270 | 1.50 | 475 | 0.90 |
| 70 | 5.35 | 275 | 2.00 | 480 | 0.80 |
| 75 | 5.35 | 280 | 2.02 | 485 | 0.65 |
| 80 | 5.30 | 285 | 2.15 | 490 | 0.55 |
| 85 | 5.30 | 290 | 2.70 | 495 | 0.55 |
| 90 | 5.30 | 295 | 3.10 | 500 | 0.60 |
| 95 | 5.30 | 300 | 3.00 | 505 | 0.60 |
| 100 | 5.25 | 305 | 3.00 | 510 | 0.60 |
| 105 | 5.25 | 310 | 2.70 | 515 | 0.60 |
| 110 | 5.25 | 315 | 2.50 | 520 | 0.55 |
| 115 | 5.25 | 320 | 2.30 | 525 | 0.50 |
| 120 | 5.20 | 325 | 2.30 | 530 | 0.45 |
| 125 | 5.15 | 330 | 2.45 | [illegible] | 0.45 |
| 130 | 5.10 | 335 | 2.25 | 540 | 0.40 |
| 135 | 5.15 | 340 | 2.05 | [illegible] | [illegible] |
| 140 | 5.20 | 345 | 2.10 | 550 | 0.40 |
| 145 | 5.20 | 350 | 2.20 | 555 | 0.30 |
| 150 | 5.20 | 355 | 2.20 | [illegible] | 0.30 |
| 155 | 5.20 | 360 | 2.05 | [illegible] | [illegible] |
| 160 | 5.20 | [illegible] | [illegible] | [illegible] | [illegible] |
| 165 | 4.90 | 370 | 1.7[illegible] | [illegible] | [illegible] |
| 170 | 3.90 | [illegible] | [illegible] | 58[illegible] | 0.15 |
| 175 | 3.55 | 380 | 0.35 | [illegible] | [illegible] |
| 180 | 4.05 | 385 | 0.2[illegible] | 590 | 0.10 |
| 185 | 4.35 | 390 | 0.50 | [illegible] | 0.10 |
| 190 | 4.60 | 395 | [illegible] | [illegible] | [illegible] |
| 195 | 4.55 | 400 | [illegible] | [illegible] | 0.10 |
| 200 | 4.45 | 405 | [illegible] | [illegible] | 0.10 |
| 205 | 4.40 | 410 | [illegible] | | |

TABLE C-5. UNCORRECTED HALON CONCENTRATION DATA, PROBE H5, TEST 1, SERIES A.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 5 | 0.25 | 200 | 1.45 | 395 | 0.50 |
| 10 | 1.05 | 205 | 1.45 | 400 | 0.50 |
| 15 | 2.15 | 210 | 1.40 | 405 | 0.50 |
| 20 | 3.05 | 215 | 1.40 | 410 | 0.50 |
| 25 | 3.75 | 220 | 1.35 | 415 | 0.50 |
| 30 | 4.20 | 225 | 1.25 | 420 | 0.50 |
| 35 | 4.40 | 230 | 1.20 | 425 | 0.45 |
| 40 | 4.45 | 235 | 1.05 | 430 | 0.40 |
| 45 | 4.35 | 240 | 0.95 | 435 | 0.35 |
| 50 | 4.15 | 245 | 0.90 | 440 | 0.30 |
| 55 | 4.10 | 250 | 0.95 | 445 | 0.30 |
| 60 | 4.10 | 255 | 1.00 | 450 | 0.30 |
| 65 | 4.15 | 260 | 1.05 | 455 | 0.30 |
| 70 | 4.15 | 265 | 1.00 | 460 | 0.35 |
| 75 | 4.20 | 270 | 0.90 | 465 | 0.40 |
| 80 | 4.20 | 275 | 0.85 | 470 | 0.40 |
| 85 | 4.10 | 280 | 0.80 | 475 | 0.40 |
| 90 | 4.05 | 285 | 0.75 | 480 | 0.35 |
| 95 | 4.00 | 290 | 0.75 | 485 | 0.30 |
| 100 | 3.85 | 295 | 0.70 | 490 | 0.25 |
| 105 | 3.65 | 300 | 0.65 | 495 | 0.20 |
| 110 | 3.70 | 305 | 0.70 | 500 | 0.20 |
| 115 | 3.75 | 310 | 0.75 | 505 | 0.20 |
| 120 | 3.60 | 315 | 0.75 | 510 | 0.20 |
| 125 | 3.15 | 320 | 0.80 | 515 | 0.20 |
| 130 | 2.75 | 325 | 0.75 | 520 | 0.20 |
| 135 | 2.55 | 330 | 0.65 | 525 | 0.20 |
| 140 | 2.40 | 335 | 0.60 | 530 | 0.20 |
| 145 | 2.30 | 340 | 0.55 | 535 | 0.20 |
| 150 | 2.20 | 345 | 0.50 | 540 | 0.45 |
| 155 | 2.15 | 350 | 0.50 | 545 | 0.35 |
| 160 | 2.05 | 355 | 0.45 | 550 | 0.25 |
| 165 | 1.95 | 360 | 0.40 | 555 | 0.20 |
| 170 | 1.85 | 365 | 0.40 | 560 | 0.10 |
| 175 | 1.75 | 370 | 0.35 | 565 | 0.10 |
| 180 | 1.70 | 375 | 0.35 | 570 | 0.05 |
| 185 | 1.65 | 380 | 0.35 | 575 | 0.05 |
| 190 | 1.60 | 385 | 0.35 | 580 | 0.05 |
| 195 | 1.55 | 390 | 0.45 | | |

TABLE C-6. *UNCORRECTED HALON CONCENTRATION DATA, PROBE H6, TEST 1, SERIES A.*

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 5 | 1.60 | 200 | 4.85 | 395 | [illegible] |
| 10 | 3.30 | 205 | 4.60 | 400 | 1.55 |
| 15 | 4.15 | 210 | 4.45 | 405 | [illegible] |
| 20 | 4.35 | 215 | 4.10 | 410 | [illegible] |
| 25 | 4.70 | 220 | 3.50 | 415 | 1.50 |
| 30 | 5.10 | 225 | 2.95 | 420 | 1.60 |
| 35 | 5.25 | 230 | 2.50 | 425 | 1.40 |
| 40 | 5.40 | 235 | 2.20 | 430 | [illegible] |
| 45 | 5.35 | 240 | 1.95 | 435 | [illegible] |
| 50 | [illegible] | 245 | 2.25 | 440 | 1.00 |
| 55 | 5.15 | 250 | 2.80 | 445 | [illegible] |
| 60 | 5.15 | 255 | 3.05 | 450 | [illegible] |
| 65 | 5.15 | 260 | 3.35 | 455 | [illegible] |
| 70 | 5.10 | 265 | 3.35 | 460 | 0.75 |
| 75 | 5.10 | 270 | 3.00 | 465 | 0.75 |
| 80 | [illegible] | 275 | 2.60 | 470 | [illegible] |
| 85 | 5.15 | 280 | 2.40 | 475 | 0.75 |
| 90 | 5.15 | 285 | 2.65 | 480 | [illegible] |
| 95 | 5.25 | 290 | 2.75 | 485 | 0.70 |
| 100 | 5.15 | 295 | 2.60 | 490 | [illegible] |
| 105 | 5.15 | 300 | 2.55 | 495 | [illegible] |
| 110 | 5.15 | 305 | 2.65 | 500 | 0.55 |
| 115 | 5.20 | 310 | 2.45 | 505 | 0.45 |
| 120 | 5.20 | 315 | 2.40 | 510 | 0.40 |
| 125 | 5.20 | 320 | 2.30 | 515 | [illegible] |
| 130 | [illegible] | 325 | 2.15 | 520 | [illegible] |
| 135 | 5.10 | 330 | [illegible] | 525 | [illegible] |
| 140 | [illegible] | 335 | [illegible] | 530 | [illegible] |
| 145 | 5.10 | 340 | 1.50 | 535 | [illegible] |
| 150 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 155 | [illegible] | 350 | [illegible] | [illegible] | [illegible] |
| 160 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 165 | [illegible] | 360 | [illegible] | [illegible] | [illegible] |
| 170 | 4.90 | [illegible] | [illegible] | [illegible] | [illegible] |
| 175 | 4.85 | 370 | [illegible] | 565 | [illegible] |
| 180 | 4.75 | [illegible] | [illegible] | [illegible] | 0.20 |
| 185 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 190 | [illegible] | 385 | [illegible] | [illegible] | [illegible] |
| 195 | 4.75 | [illegible] | [illegible] | [illegible] | [illegible] |

TABLE C-7. UNCORRECTED HALON CONCENTRATION DATA, PROBE H1, TEST 2, SERIES A.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 5 | 0.15 | 130 | 1.00 | 255 | 0.15 |
| 10 | 0.50 | 135 | 0.85 | 260 | 0.15 |
| 15 | 1.35 | 140 | 0.80 | 265 | 0.15 |
| 20 | 2.50 | 145 | 0.75 | 270 | 0.15 |
| 25 | 3.55 | 150 | 0.70 | 275 | 0.15 |
| 30 | 3.65 | 155 | 0.65 | 280 | 0.10 |
| 35 | 3.30 | 160 | 0.55 | 285 | 0.10 |
| 40 | 3.40 | 165 | 0.45 | 290 | 0.10 |
| 45 | 3.40 | 170 | 0.35 | 295 | 0.10 |
| 50 | 3.00 | 175 | 0.30 | 300 | 0.10 |
| 55 | 2.85 | 180 | 0.25 | 305 | 0.10 |
| 60 | 2.85 | 185 | 0.25 | 310 | 0.10 |
| 65 | 3.10 | 190 | 0.20 | 315 | 0.10 |
| 70 | 3.10 | 195 | 0.15 | 320 | 0.10 |
| 75 | 3.15 | 200 | 0.15 | 325 | 0.10 |
| 80 | 2.80 | 205 | 0.15 | 330 | 0.10 |
| 85 | 2.50 | 210 | 0.15 | 335 | 0.10 |
| 90 | 2.15 | 215 | 0.15 | 340 | 0.70 |
| 95 | 1.95 | 220 | 0.15 | 345 | 0.50 |
| 100 | 1.85 | 225 | 0.15 | 350 | 0.35 |
| 105 | 1.80 | 230 | 0.15 | 355 | 0.25 |
| 110 | 1.70 | 235 | 0.15 | 360 | 0.20 |
| 115 | 1.50 | 240 | 0.15 | 365 | 0.15 |
| 120 | 1.25 | 245 | 0.15 | 370 | 0.10 |
| 125 | 1.10 | 250 | 0.15 | | |

TABLE C-8. UNCORRECTED HALON CONCENTRATION DATA, PROBE H2, TEST 2, SERIES A.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 5 | 0.10 | 135 | 0.60 | 265 | 0.10 |
| 10 | 0.55 | 140 | 0.50 | 270 | 0.10 |
| 15 | 1.80 | 145 | 0.45 | 275 | 0.05 |
| 20 | 3.15 | 150 | 0.40 | 280 | 0.00 |
| 25 | 4.35 | 155 | 0.40 | 285 | 0.00 |
| 30 | 4.00 | 160 | 0.40 | 290 | 0.00 |
| 35 | 3.65 | 165 | 0.35 | 295 | 0.00 |
| 40 | 2.75 | 170 | 0.30 | 300 | 0.05 |
| 45 | 2.20 | 175 | 0.30 | 305 | 0.05 |
| 50 | 1.80 | 180 | 0.25 | 310 | 0.05 |
| 55 | 1.45 | 185 | 0.25 | 315 | 0.05 |
| 60 | 1.15 | 190 | 0.25 | 320 | 0.05 |
| 65 | 1.00 | 195 | 0.20 | 325 | 0.05 |
| 70 | 0.95 | 200 | 0.20 | 330 | 0.05 |
| 75 | 0.75 | 205 | 0.20 | 335 | 0.05 |
| 80 | 0.75 | 210 | 0.20 | 340 | 0.30 |
| 85 | 0.75 | 215 | 0.20 | 345 | 0.25 |
| 90 | 0.80 | 220 | 0.20 | 350 | 0.20 |
| 95 | 0.85 | 225 | 0.20 | 355 | 0.10 |
| 100 | 0.90 | 230 | 0.15 | 360 | 0.05 |
| 105 | 0.95 | 235 | 0.15 | 365 | 0.05 |
| 110 | 0.95 | 240 | 0.15 | 370 | 0.00 |
| 115 | 0.95 | 245 | 0.15 | 375 | 0.00 |
| 120 | 0.90 | 250 | 0.10 | 380 | 0.00 |
| 125 | 0.80 | 255 | 0.10 | | |
| 130 | 0.75 | 260 | 0.10 | | |

TABLE C-9. UNCORRECTED HALON CONCENTRATION DATA, PROBE H3, TEST 2, SERIES A.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 5 | 0.85 | 130 | 1.30 | 255 | 0.40 |
| 10 | 2.55 | 135 | 1.15 | 260 | 0.40 |
| 15 | 4.30 | 140 | 1.05 | 265 | 0.40 |
| 20 | 5.25 | 145 | 1.00 | 270 | 0.35 |
| 25 | 5.40 | 150 | 0.95 | 275 | 0.30 |
| 30 | 4.90 | 155 | 0.90 | 280 | 0.30 |
| 35 | 4.40 | 160 | 0.90 | 285 | 0.25 |
| 40 | 3.90 | 165 | 0.85 | 290 | 0.25 |
| 45 | 3.80 | 170 | 0.80 | 295 | 0.25 |
| 50 | 4.00 | 175 | 0.70 | 300 | 0.25 |
| 55 | 4.05 | 180 | 0.70 | 305 | 0.25 |
| 60 | 4.00 | 185 | 0.65 | 310 | 0.25 |
| 65 | 3.70 | 190 | 0.65 | 315 | 0.25 |
| 70 | 3.35 | 195 | 0.65 | 320 | 0.25 |
| 75 | 3.00 | 200 | 0.60 | 325 | 0.20 |
| 80 | 2.75 | 205 | 0.50 | 330 | 0.20 |
| 85 | 2.60 | 210 | 0.45 | 335 | 0.20 |
| 90 | 2.45 | 215 | 0.40 | 340 | 0.20 |
| 95 | 2.25 | 220 | 0.40 | 345 | 0.50 |
| 100 | 2.05 | 225 | 0.40 | 350 | 0.35 |
| 105 | 1.90 | 230 | 0.40 | 355 | 0.30 |
| 110 | 1.80 | 235 | 0.45 | 360 | 0.25 |
| 115 | 1.65 | 240 | 0.40 | 365 | 0.20 |
| 120 | 1.55 | 245 | 0.40 | 370 | 0.20 |
| 125 | 1.40 | 250 | 0.40 | 375 | 0.15 |

TABLE C-10. UNCORRECTED HALON CONCENTRATION DATA, PROBE H4, TEST 2, SERIES A.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 5 | 0.20 | 130 | 0.95 | 255 | 0.20 |
| 10 | 0.30 | 135 | 0.95 | 260 | 0.20 |
| 15 | 2.40 | 140 | 0.90 | 265 | 0.20 |
| 20 | 4.40 | 145 | 0.85 | 270 | 0.20 |
| 25 | 5.20 | 150 | 0.75 | 275 | 0.15 |
| 30 | 5.05 | 155 | 0.65 | 280 | 0.15 |
| 35 | 4.15 | 160 | 0.55 | 285 | 0.15 |
| 40 | 3.75 | 165 | 0.50 | 290 | 0.15 |
| 45 | 3.70 | 170 | 0.40 | 295 | 0.15 |
| 50 | 3.05 | 175 | 0.35 | 300 | 0.15 |
| 55 | 2.70 | 180 | 0.35 | 305 | 0.15 |
| 60 | 2.65 | 185 | 0.30 | 310 | 0.15 |
| 65 | 2.85 | 190 | 0.30 | 315 | 0.15 |
| 70 | 2.75 | 195 | 0.30 | 320 | 0.15 |
| 75 | 2.55 | 200 | 0.25 | 325 | 0.15 |
| 80 | 2.35 | 205 | 0.25 | 330 | 0.15 |
| 85 | 1.35 | 210 | 0.25 | 335 | 0.15 |
| 90 | 1.65 | 215 | 0.25 | 340 | 0.10 |
| 95 | 1.40 | 220 | 0.25 | 345 | 0.10 |
| 100 | 1.35 | 225 | 0.25 | 350 | 0.20 |
| 105 | 1.35 | 230 | 0.25 | 355 | 0.00 |
| 110 | 1.30 | 235 | 0.25 | 360 | 0.00 |
| 115 | 1.20 | 240 | 0.25 | 365 | 0.00 |
| 120 | 1.05 | 245 | 0.25 | | |
| 125 | 1.00 | 250 | 0.25 | | |

TABLE C-11. UNCORRECTED HALON CONCENTRATION DATA, PROBE H5, TEST 2, SERIES A.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 5 | 0.25 | 100 | 0.95 | 195 | 0.20 |
| 10 | 1.40 | 105 | 0.85 | 200 | 0.15 |
| 15 | 3.00 | 110 | 0.80 | 205 | 0.15 |
| 20 | 4.60 | 115 | 0.85 | 210 | 0.15 |
| 25 | 5.25 | 120 | 0.75 | 215 | 0.15 |
| 30 | 4.35 | 125 | 0.70 | 220 | 0.15 |
| 35 | 3.25 | 130 | 0.60 | 225 | 0.15 |
| 40 | 2.20 | 135 | 0.50 | 230 | 0.15 |
| 45 | 1.65 | 140 | 0.45 | 235 | 0.10 |
| 50 | 1.30 | 145 | 0.40 | 240 | 0.10 |
| 55 | 1.20 | 150 | 0.40 | 245 | 0.10 |
| 60 | 1.35 | 155 | 0.35 | 250 | 0.15 |
| 65 | 1.30 | 160 | 0.35 | 255 | 0.10 |
| 70 | 1.00 | 165 | 0.25 | 260 | 0.05 |
| 75 | 0.75 | 170 | 0.25 | 265 | 0.05 |
| 80 | 0.70 | 175 | 0.25 | 270 | 0.05 |
| 85 | 0.70 | 180 | 0.20 | 275 | 0.05 |
| 90 | 0.85 | 185 | 0.20 | | |
| 95 | 0.95 | 190 | 0.15 | | |

TABLE C-12. UNCORRECTED HALON CONCENTRATION DATA, PROBE H6, TEST 2, SERIES A.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 5 | 0.65 | 130 | 0.95 | 255 | 0.25 |
| 10 | 2.40 | 135 | 0.90 | 260 | 0.20 |
| 15 | 4.15 | 140 | 0.80 | 265 | 0.20 |
| 20 | 5.15 | 145 | 0.75 | 270 | 0.20 |
| 25 | 5.40 | 150 | 0.65 | 275 | 0.15 |
| 30 | 5.00 | 155 | 0.55 | 280 | 0.15 |
| 35 | 4.40 | 160 | 0.45 | 285 | 0.15 |
| 40 | 3.80 | 165 | 0.40 | 290 | 0.15 |
| 45 | 3.45 | 170 | 0.40 | 295 | 0.15 |
| 50 | 3.15 | 175 | 0.40 | 300 | 0.15 |
| 55 | 2.95 | 180 | 0.40 | 305 | 0.15 |
| 60 | 3.10 | 185 | 0.40 | 310 | 0.15 |
| 65 | 2.80 | 190 | 0.40 | 315 | 0.15 |
| 70 | 2.35 | 195 | 0.35 | 320 | 0.10 |
| 75 | 2.60 | 200 | 0.35 | 325 | 0.25 |
| 80 | 2.55 | 205 | 0.35 | 330 | 0.20 |
| 85 | 2.15 | 210 | 0.35 | 335 | 0.20 |
| 90 | 1.85 | 215 | 0.30 | 340 | 0.20 |
| 95 | 1.50 | 220 | 0.30 | 345 | 0.10 |
| 100 | 1.40 | 225 | 0.30 | 350 | 0.10 |
| 105 | 1.25 | 230 | 0.25 | 355 | 0.10 |
| 110 | 1.15 | 235 | 0.25 | 360 | 0.05 |
| 115 | 1.10 | 240 | 0.25 | 365 | 0.05 |
| 120 | 1.05 | 245 | 0.25 | 370 | 0.05 |
| 125 | 1.00 | 250 | 0.30 | 375 | 0.05 |

TABLE C-13. UNCORRECTED HALON CONCENTRATION DATA, PROBE H1, TEST 1, SERIES B.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 5 | 0.15 | 95 | 4.15 | 185 | 2.20 |
| 10 | 0.45 | 100 | 4.30 | 190 | 2.15 |
| 15 | 0.75 | 105 | 4.50 | 195 | 1.90 |
| 20 | 1.10 | 110 | 4.70 | 200 | 1.60 |
| 25 | 1.45 | 115 | 4.85 | 205 | 1.40 |
| 30 | 1.70 | 120 | 4.95 | 210 | 1.05 |
| 35 | 2.00 | 125 | 5.00 | 215 | 0.90 |
| 40 | 2.30 | 130 | 4.90 | 220 | 0.75 |
| 45 | 2.60 | 135 | 4.80 | 225 | 0.60 |
| 50 | 2.70 | 140 | 4.75 | 230 | 0.50 |
| 55 | 2.75 | 145 | 4.70 | 235 | 0.40 |
| 60 | 2.90 | 150 | 4.70 | 240 | 0.30 |
| 65 | 3.00 | 155 | 4.65 | 245 | 0.25 |
| 70 | 3.20 | 160 | 4.50 | 250 | 0.20 |
| 75 | 3.40 | 165 | 4.20 | 255 | 0.20 |
| 80 | 3.65 | 170 | 2.95 | 260 | 0.15 |
| 85 | 3.85 | 175 | 2.05 | 265 | 0.15 |
| 90 | 4.00 | 180 | 1.95 | | |

TABLE C-14. UNCORRECTED HALON CONCENTRATION DATA, PROBE H2, TEST 1, SERIES B.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 5 | 0.30 | 105 | 6.80 | 205 | 6.20 |
| 10 | 1.05 | 110 | 7.00 | 210 | 6.20 |
| 15 | 1.95 | 115 | 7.10 | 215 | 5.20 |
| 20 | 3.05 | 120 | 7.05 | 220 | 4.60 |
| 25 | 4.30 | 125 | 6.95 | 225 | 3.20 |
| 30 | 5.65 | 130 | 6.85 | 230 | 2.20 |
| 35 | 6.50 | 135 | 6.85 | 235 | 1.60 |
| 40 | 7.05 | 140 | 6.90 | 240 | 1.30 |
| 45 | 7.25 | 145 | 6.90 | 245 | 1.05 |
| 50 | 7.15 | 150 | 6.85 | 250 | 0.95 |
| 55 | 6.65 | 155 | 6.90 | 255 | 0.85 |
| 60 | 5.95 | 160 | 6.95 | 260 | 0.80 |
| 65 | 5.50 | 165 | 6.90 | 265 | 0.75 |
| 70 | 5.65 | 170 | 6.75 | 270 | 0.75 |
| 75 | 5.85 | 175 | 6.75 | 275 | 0.70 |
| 80 | 5.90 | 180 | 6.60 | 280 | 0.70 |
| 85 | 6.00 | 185 | 6.60 | 285 | 0.70 |
| 90 | 6.10 | 190 | 6.45 | 290 | 0.70 |
| 95 | 6.40 | 195 | 6.40 | 295 | 0.70 |
| 100 | 6.60 | 200 | 6.30 | | |

TABLE C-15. UNCORRECTED HALON CONCENTRATION DATA, PROBE H3, TEST 1, SERIES B.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 5 | 0.20 | 85 | 5.70 | 165 | 3.55 |
| 10 | 0.80 | 90 | 5.60 | 170 | 3.45 |
| 15 | 1.90 | 95 | 5.40 | 175 | 3.30 |
| 20 | 3.00 | 100 | 5.20 | 180 | 3.20 |
| 25 | 3.70 | 105 | 5.10 | 185 | 3.05 |
| 30 | 4.40 | 110 | 4.95 | 190 | 2.95 |
| 35 | 4.70 | 115 | 4.60 | 195 | 2.90 |
| 40 | 4.75 | 120 | 4.30 | 200 | 2.90 |
| 45 | 4.90 | 125 | 4.05 | 205 | 1.90 |
| 50 | 5.00 | 130 | 4.00 | 210 | 1.75 |
| 55 | 5.05 | 135 | 4.20 | 215 | 1.20 |
| 60 | 5.40 | 140 | 4.15 | 220 | 1.15 |
| 65 | 5.50 | 145 | 3.95 | 225 | 0.70 |
| 70 | 5.50 | 150 | 3.80 | 230 | 0.10 |
| 75 | 5.60 | 155 | 3.70 | | |
| 80 | 5.70 | 160 | 3.65 | | |

TABLE C-16. UNCORRECTED HALON CONCENTRATION DATA, PROBE H4, TEST 1, SERIES B.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 5 | 0.10 | 105 | 6.85 | 205 | 6.00 |
| 10 | 0.30 | 110 | 6.70 | 210 | 5.90 |
| 15 | 1.00 | 115 | 6.65 | 215 | 3.20 |
| 20 | 1.60 | 120 | 6.65 | 220 | 2.90 |
| 25 | 3.50 | 125 | 6.65 | 225 | 2.20 |
| 30 | 4.90 | 130 | 6.65 | 230 | 1.90 |
| 35 | 5.70 | 135 | 6.65 | 235 | 1.40 |
| 40 | 5.80 | 140 | 6.65 | 240 | 1.00 |
| 45 | 6.30 | 145 | 6.60 | 245 | 1.00 |
| 50 | 6.50 | 150 | 6.50 | 250 | 0.00 |
| 55 | 6.55 | 155 | 6.40 | 255 | 0.40 |
| 60 | 6.60 | 160 | 6.50 | 260 | 0.30 |
| 65 | 6.70 | 165 | 6.40 | 265 | 0.20 |
| 70 | 6.80 | 170 | 6.40 | 270 | 0.20 |
| 75 | 6.95 | 175 | 6.40 | 275 | 0.20 |
| 80 | 7.00 | 180 | 6.20 | 280 | 0.10 |
| 85 | 6.90 | 185 | 5.95 | 285 | 0.10 |
| 90 | 6.95 | 190 | 5.95 | 290 | 0.10 |
| 95 | 6.95 | 195 | 6.10 | | |
| 100 | 6.85 | 200 | 6.20 | | |

TABLE C-17. UNCORRECTED HALON CONCENTRATION DATA, PROBE H5, TEST 1, SERIES B.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 5 | 0.10 | 100 | 5.40 | 195 | 2.95 |
| 10 | 0.45 | 105 | 5.20 | 200 | 2.65 |
| 15 | 1.20 | 110 | 4.90 | 205 | 2.05 |
| 20 | 2.15 | 115 | 4.60 | 210 | 2.00 |
| 25 | 3.10 | 120 | 4.35 | 215 | 1.70 |
| 30 | 3.85 | 125 | 4.35 | 220 | 1.70 |
| 35 | 4.40 | 130 | 4.35 | 225 | 1.70 |
| 40 | 4.85 | 135 | 4.30 | 230 | 1.20 |
| 45 | 5.20 | 140 | 4.30 | 235 | 0.60 |
| 50 | 5.35 | 145 | 4.25 | 240 | 0.50 |
| 55 | 5.45 | 150 | 4.10 | 245 | 0.35 |
| 60 | 5.50 | 155 | 3.90 | 250 | 0.25 |
| 65 | 5.55 | 160 | 3.75 | 255 | 0.20 |
| 70 | 5.55 | 165 | 3.55 | 260 | 0.10 |
| 75 | 5.65 | 170 | 3.45 | 265 | 0.05 |
| 80 | 5.65 | 175 | 3.35 | 270 | 0.05 |
| 85 | 5.60 | 180 | 3.30 | 275 | 0.05 |
| 90 | 5.55 | 185 | 3.20 | 280 | 0.05 |
| 95 | 5.45 | 190 | 3.10 | | |

TABLE C-18. UNCORRECTED HALON CONCENTRATION DATA, PROBE H6, TEST 1, SERIES B.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 5 | 0.45 | 100 | 7.50 | 195 | 6.15 |
| 10 | 1.15 | 105 | 7.50 | 200 | 6.15 |
| 15 | 1.85 | 110 | 7.50 | 205 | 4.40 |
| 20 | 2.65 | 115 | 7.35 | 210 | 3.85 |
| 25 | 3.75 | 120 | 7.25 | 215 | 3.40 |
| 30 | 4.90 | 125 | 7.20 | 220 | 2.85 |
| 35 | 5.75 | 130 | 7.25 | 225 | 2.05 |
| 40 | 6.35 | 135 | 7.20 | 230 | 1.50 |
| 45 | 6.70 | 140 | 7.05 | 235 | 1.15 |
| 50 | 6.85 | 145 | 7.10 | 240 | 0.95 |
| 55 | 7.00 | 150 | 7.15 | 245 | 0.75 |
| 60 | 7.15 | 155 | 7.10 | 250 | 0.60 |
| 65 | 7.30 | 160 | 7.00 | 255 | 0.55 |
| 70 | 7.35 | 165 | 6.80 | 260 | 0.50 |
| 75 | 7.40 | 170 | 6.70 | 265 | 0.45 |
| 80 | 7.45 | 175 | 6.60 | 270 | 0.45 |
| 85 | 7.45 | 180 | 6.40 | 275 | 0.45 |
| 90 | 7.45 | 185 | 6.20 | | |
| 95 | 7.45 | 190 | 6.10 | | |

TABLE C-19. UNCORRECTED HALON CONCENTRATION DATA, PROBE H1, TEST 2, SERIES B.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 5 | 0.10 | 40 | 1.45 | 75 | 0.65 |
| 10 | 0.25 | 45 | 2.40 | 80 | 0.50 |
| 15 | 0.50 | 50 | 2.20 | 85 | 0.40 |
| 20 | 0.80 | 55 | 1.80 | 90 | 0.25 |
| 25 | 1.15 | 60 | 1.45 | 95 | 0.20 |
| 30 | 1.45 | 65 | 1.15 | 100 | 0.15 |
| 35 | 1.45 | 70 | 0.85 | 105 | 0.15 |

TABLE C-20. UNCORRECTED HALON CONCENTRATION DATA, PROBE H2, TEST 2, SERIES B.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 5 | 0.25 | 45 | 4.05 | 85 | 0.30 |
| 10 | 0.75 | 50 | 3.90 | 90 | 0.20 |
| 15 | 1.95 | 55 | 2.55 | 95 | 0.20 |
| 20 | 3.45 | 60 | 1.60 | 100 | 0.20 |
| 25 | 4.65 | 65 | 1.00 | 105 | 0.20 |
| 30 | 5.20 | 70 | 0.70 | 110 | 0.20 |
| 35 | 5.20 | 75 | 0.50 | | |
| 40 | 5.00 | 80 | 0.40 | | |

TABLE C-21. UNCORRECTED HALON CONCENTRATION DATA, PROBE H3, TEST 2, SERIES B.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 5 | 0.25 | 45 | 3.95 | 85 | 0.45 |
| 10 | 1.15 | 50 | 4.05 | 90 | 0.30 |
| 15 | 2.00 | 55 | 3.85 | 95 | 0.20 |
| 20 | 3.20 | 60 | 2.90 | 100 | 0.10 |
| 25 | 4.70 | 65 | 1.80 | 105 | 0.05 |
| 30 | 5.30 | 70 | 1.80 | 110 | 0.05 |
| 35 | 4.90 | 75 | 1.10 | 115 | 0.05 |
| 40 | 4.20 | 80 | 0.70 | | |

TABLE C-22. UNCORRECTED HALON CONCENTRATION DATA, PROBE H4, TEST 2, SERIES B.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 5 | 0.15 | 45 | 4.75 | 85 | 0.80 |
| 10 | 1.30 | 50 | 4.65 | 90 | 0.50 |
| 15 | 2.40 | 55 | 4.95 | 95 | 0.35 |
| 20 | 3.70 | 60 | 4.35 | 100 | 0.25 |
| 25 | 5.05 | 65 | 3.30 | 105 | 0.20 |
| 30 | 6.20 | 70 | 3.10 | 110 | 0.20 |
| 35 | 6.35 | 75 | 2.00 | 115 | 0.20 |
| 40 | 5.50 | 80 | 1.20 | | |

TABLE C-23. UNCORRECTED HALON CONCENTRATION DATA, PROBE H5, TEST 2, SERIES B.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 5 | 0.15 | 50 | 2.55 | 95 | 0.30 |
| 10 | 0.25 | 55 | 1.85 | 100 | 0.25 |
| 15 | 0.60 | 60 | 1.65 | 105 | 0.20 |
| 20 | 1.10 | 65 | 1.90 | 110 | 0.10 |
| 25 | 1.60 | 70 | 1.40 | 115 | 0.05 |
| 30 | 1.95 | 75 | 1.00 | 120 | 0.10 |
| 35 | 2.35 | 80 | 0.70 | 125 | 0.10 |
| 40 | 2.60 | 85 | 0.50 | 130 | 0.10 |
| 45 | 2.85 | 90 | 0.40 | | |

TABLE C-24. UNCORRECTED HALON CONCENTRATION DATA, PROBE H6, TEST 2, SERIES B.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 5 | 0.20 | 45 | 2.90 | 85 | 0.35 |
| 10 | 0.45 | 50 | 2.10 | 90 | 0.30 |
| 15 | 1.00 | 55 | 1.70 | 95 | 0.25 |
| 20 | 1.55 | 60 | 1.45 | 100 | 0.25 |
| 25 | 2.10 | 65 | 1.00 | 105 | 0.20 |
| 30 | 2.65 | 70 | 0.75 | 110 | 0.20 |
| 35 | 3.40 | 75 | 0.55 | | |
| 40 | 3.00 | 80 | 0.45 | | |

TABLE C-25. UNCORRECTED HALON CONCENTRATION DATA, PROBE H1, TEST 2, SERIES C.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 5 | 0.25 | 170 | 1.00 | 335 | 0.35 |
| 10 | 0.65 | 175 | 1.00 | 340 | 0.40 |
| 15 | 1.05 | 180 | 0.95 | 345 | 0.40 |
| 20 | 1.45 | 185 | 0.90 | 350 | 0.40 |
| 25 | 1.75 | 190 | 0.85 | 355 | 0.35 |
| 30 | 1.95 | 195 | 0.80 | 360 | 0.35 |
| 35 | 2.20 | 200 | 0.80 | 365 | 0.35 |
| 40 | 2.35 | 205 | 0.75 | 370 | 0.35 |
| 45 | 2.45 | 210 | 0.75 | 375 | 0.35 |
| 50 | 2.50 | 215 | 0.75 | 380 | 0.25 |
| 55 | 2.55 | 220 | 0.70 | 385 | 0.25 |
| 60 | 2.55 | 225 | 0.65 | 390 | 0.25 |
| 65 | 2.55 | 230 | 0.60 | 395 | 0.25 |
| 70 | 2.45 | 235 | 0.60 | 400 | 0.25 |
| 75 | 2.35 | 240 | 0.55 | 405 | 0.20 |
| 80 | 2.30 | 245 | 0.55 | 410 | 0.25 |
| 85 | 2.20 | 250 | 0.55 | 415 | 0.25 |
| 90 | 2.10 | 255 | 0.50 | 420 | 0.25 |
| 95 | 2.00 | 260 | 0.55 | 425 | 0.20 |
| 100 | 1.90 | 265 | 0.55 | 430 | 0.15 |
| 105 | 1.80 | 270 | 0.55 | 435 | 0.15 |
| 110 | 1.75 | 275 | 0.50 | 440 | 0.15 |
| 115 | 1.65 | 280 | 0.45 | 445 | 0.15 |
| 120 | 1.60 | 285 | 0.45 | 450 | 0.15 |
| 125 | 1.55 | 290 | 0.45 | 455 | 0.10 |
| 130 | 1.45 | 295 | 0.40 | 460 | 0.15 |
| 135 | 1.40 | 300 | 0.40 | 465 | 0.15 |
| 140 | 1.35 | 305 | 0.35 | 470 | 0.15 |
| 145 | 1.25 | 310 | 0.35 | 475 | 0.10 |
| 150 | 1.20 | 315 | 0.35 | 480 | 0.05 |
| 155 | 1.15 | 320 | 0.35 | 485 | 0.10 |
| 160 | 1.05 | 325 | 0.35 | 490 | 0.10 |
| 165 | 1.05 | 330 | 0.35 | | |

TABLE C-26. UNCORRECTED HALON CONCENTRATION DATA, PROBE H2, TEST 2, SERIES C.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 5 | 0.25 | 170 | 2.10 | 335 | 1.15 |
| 10 | 1.50 | 175 | 2.05 | 340 | 1.10 |
| 15 | 3.00 | 180 | 1.95 | 345 | 1.10 |
| 20 | 4.30 | 185 | 1.85 | 350 | 1.05 |
| 25 | 5.25 | 190 | 1.85 | 355 | 0.95 |
| 30 | 5.80 | 195 | 1.80 | 360 | 0.85 |
| 35 | 6.05 | 200 | 1.80 | 365 | 0.95 |
| 40 | 6.30 | 205 | 1.75 | 370 | 1.00 |
| 45 | 6.45 | 210 | 1.75 | 375 | 1.00 |
| 50 | 6.45 | 215 | 1.65 | 380 | 0.95 |
| 55 | 6.50 | 220 | 1.65 | 385 | 0.85 |
| 60 | 6.40 | 225 | 1.60 | 390 | 0.85 |
| 65 | 6.05 | 230 | 1.55 | 395 | 0.85 |
| 70 | 5.80 | 235 | 1.45 | 400 | 0.85 |
| 75 | 5.50 | 240 | 1.40 | 405 | 0.90 |
| 80 | 5.25 | 245 | 1.35 | 410 | 0.80 |
| 85 | 5.05 | 250 | 1.30 | 415 | 0.75 |
| 90 | 4.85 | 255 | 1.30 | 420 | 0.70 |
| 95 | 4.55 | 260 | 1.30 | 425 | 0.70 |
| 100 | 4.45 | 265 | 1.25 | 430 | 0.60 |
| 105 | 4.05 | 270 | 1.30 | 435 | 0.60 |
| 110 | 3.70 | 275 | 1.20 | 440 | 0.60 |
| 115 | 3.50 | 280 | 1.25 | 445 | 0.60 |
| 120 | 3.30 | 285 | 1.20 | 450 | 0.60 |
| 125 | 3.05 | 290 | 1.20 | 455 | 0.60 |
| 130 | 2.90 | 295 | 1.20 | 460 | 0.60 |
| 135 | 2.75 | 300 | 1.15 | 465 | 0.60 |
| 140 | 2.65 | 305 | 1.20 | 470 | 0.60 |
| 145 | 2.55 | 310 | 1.20 | 475 | 0.60 |
| 150 | 2.45 | 315 | 1.15 | 480 | 0.60 |
| 155 | 2.35 | 320 | 1.15 | 485 | 0.60 |
| 160 | 2.20 | 325 | 1.15 | 490 | 0.60 |
| 165 | 2.15 | 330 | 1.15 | | |

TABLE C-27. UNCORRECTED HALON CONCENTRATION DATA, PROBE H3, TEST 2, SERIES C.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 5 | 0.30 | 175 | 0.85 | 345 | 0.50 |
| 10 | 0.70 | 180 | 0.80 | 350 | 0.50 |
| 15 | 1.25 | 185 | 0.80 | 355 | 0.50 |
| 20 | 1.95 | 190 | 0.80 | 360 | 0.50 |
| 25 | 2.60 | 195 | 0.75 | 365 | 0.50 |
| 30 | 3.05 | 200 | 0.75 | 370 | 0.55 |
| 35 | 3.10 | 205 | 0.70 | 375 | 0.50 |
| 40 | 3.00 | 210 | 0.65 | 380 | 0.50 |
| 45 | 2.85 | 215 | 0.65 | 385 | 0.45 |
| 50 | 2.80 | 220 | 0.65 | 390 | 0.45 |
| 55 | 2.80 | 225 | 0.65 | 395 | 0.45 |
| 60 | 2.60 | 230 | 0.65 | 400 | 0.45 |
| 65 | 2.35 | 235 | 0.65 | 405 | 0.45 |
| 70 | 2.15 | 240 | 0.65 | 410 | 0.45 |
| 75 | 2.00 | 245 | 0.65 | 415 | 0.45 |
| 80 | 1.85 | 250 | 0.65 | 420 | 0.45 |
| 85 | 1.80 | 255 | 0.65 | 425 | 0.40 |
| 90 | 1.70 | 260 | 0.65 | 430 | 0.40 |
| 95 | 1.60 | 265 | 0.65 | 435 | 0.40 |
| 100 | 1.50 | 270 | 0.65 | 440 | 0.40 |
| 105 | 1.40 | 275 | 0.65 | 445 | 0.35 |
| 110 | 1.35 | 280 | 0.65 | 450 | 0.35 |
| 115 | 1.30 | 285 | 0.65 | 455 | 0.35 |
| 120 | 1.30 | 290 | 0.65 | 460 | 0.35 |
| 125 | 1.25 | 295 | 0.60 | 465 | 0.35 |
| 130 | 1.15 | 300 | 0.60 | 470 | 0.35 |
| 135 | 1.10 | 305 | 0.60 | 475 | 0.35 |
| 140 | 1.05 | 310 | 0.60 | 480 | 0.35 |
| 145 | 1.00 | 315 | 0.60 | 485 | 0.35 |
| 150 | 1.00 | 320 | 0.60 | 490 | 0.35 |
| 155 | 0.95 | 325 | 0.55 | 495 | 0.35 |
| 160 | 0.95 | 330 | 0.55 | 500 | 0.35 |
| 165 | 0.90 | 335 | 0.55 | 505 | 0.35 |
| 170 | 0.85 | 340 | 0.55 | | |

TABLE C-28. UNCORRECTED HALON CONCENTRATION DATA, PROBE H5, TEST 2, SERIES C.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 5 | 0.45 | 170 | 1.55 | 335 | 0.75 |
| 10 | 1.00 | 175 | 1.50 | 340 | 0.75 |
| 15 | 1.50 | 180 | 1.45 | 345 | 0.75 |
| 20 | 1.95 | 185 | 1.40 | 350 | 0.75 |
| 25 | 2.30 | 190 | 1.35 | 355 | 0.70 |
| 30 | 2.65 | 195 | 1.25 | 360 | 0.65 |
| 35 | 2.95 | 200 | 1.25 | 365 | 0.70 |
| 40 | 3.25 | 205 | 1.20 | 370 | 0.70 |
| 45 | 3.35 | 210 | 1.20 | 375 | 0.65 |
| 50 | 3.50 | 215 | 1.20 | 380 | 0.65 |
| 55 | 3.55 | 220 | 1.15 | 385 | 0.65 |
| 60 | 3.65 | 225 | 1.10 | 390 | 0.65 |
| 65 | 3.75 | 230 | 1.05 | 395 | 0.65 |
| 70 | 3.75 | 235 | 1.05 | 400 | 0.65 |
| 75 | 3.65 | 240 | 1.00 | 405 | 0.60 |
| 80 | 3.55 | 245 | 1.00 | 410 | 0.60 |
| 85 | 3.45 | 250 | 0.95 | 415 | 0.60 |
| 90 | 3.35 | 255 | 0.95 | 420 | 0.60 |
| 95 | 3.30 | 260 | 0.95 | 425 | 0.60 |
| 100 | 3.15 | 265 | 0.95 | 430 | 0.60 |
| 105 | 3.00 | 270 | 0.90 | 435 | 0.60 |
| 110 | 2.85 | 275 | 0.90 | 440 | 0.60 |
| 115 | 2.65 | 280 | 0.85 | 445 | 0.60 |
| 120 | 2.50 | 285 | 0.85 | 450 | 0.55 |
| 125 | 2.35 | 290 | 0.85 | 455 | 0.55 |
| 130 | 2.25 | 295 | 0.85 | 460 | 0.50 |
| 135 | 2.20 | 300 | 0.85 | 465 | 0.50 |
| 140 | 2.05 | 305 | 0.80 | 470 | 0.50 |
| 145 | 1.95 | 310 | 0.80 | 475 | 0.45 |
| 150 | 1.85 | 315 | 0.80 | 480 | 0.45 |
| 155 | 1.75 | 320 | 0.80 | 485 | 0.45 |
| 160 | 1.70 | 325 | 0.75 | 490 | 0.45 |
| 165 | 1.65 | 330 | 0.75 | 495 | 0.45 |

TABLE C-29. UNCORRECTED HALON CONCENTRATION DATA, PROBE H6, TEST 2, SERIES C.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 5 | 0.35 | 165 | 2.55 | 325 | 0.95 |
| 10 | 0.95 | 170 | 2.45 | 330 | 0.95 |
| 15 | 1.65 | 175 | 2.40 | 335 | 0.95 |
| 20 | 2.55 | 180 | 2.30 | 340 | 0.95 |
| 25 | 3.50 | 185 | 2.20 | 345 | 0.95 |
| 30 | 4.25 | 190 | 2.15 | 350 | 0.95 |
| 35 | 4.70 | 195 | 2.00 | 355 | 0.95 |
| 40 | 5.05 | 200 | 1.95 | 360 | 0.90 |
| 45 | 5.45 | 205 | 1.85 | 365 | 0.85 |
| 50 | 5.70 | 210 | 1.75 | 370 | 0.90 |
| 55 | 5.85 | 215 | 1.65 | 375 | 0.85 |
| 60 | 6.00 | 220 | 1.60 | 380 | 0.85 |
| 65 | 6.15 | 225 | 1.55 | 385 | 0.80 |
| 70 | 6.15 | 230 | 1.50 | 390 | 0.80 |
| 75 | 5.90 | 235 | 1.45 | 395 | 0.80 |
| 80 | 5.65 | 240 | 1.45 | 400 | 0.75 |
| 85 | 5.30 | 245 | 1.40 | 405 | 0.75 |
| 90 | 5.05 | 250 | 1.35 | 410 | 0.75 |
| 95 | 4.95 | 255 | 1.30 | 415 | 0.75 |
| 100 | 4.55 | 260 | 1.25 | 420 | 0.70 |
| 105 | 4.15 | 265 | 1.20 | 425 | 0.65 |
| 110 | 3.75 | 270 | 1.15 | 430 | 0.70 |
| 115 | 3.55 | 275 | 1.15 | 435 | 0.65 |
| 120 | 3.45 | 280 | 1.10 | 440 | 0.65 |
| 125 | 3.40 | 285 | 1.10 | 445 | 0.60 |
| 130 | 3.25 | 290 | 1.10 | 450 | 0.65 |
| 135 | 3.15 | 295 | 1.05 | 455 | 0.65 |
| 140 | 3.00 | 300 | 1.05 | 460 | 0.60 |
| 145 | 2.85 | 305 | 1.05 | 465 | 0.60 |
| 150 | 2.75 | 310 | 1.00 | 470 | 0.55 |
| 155 | 2.65 | 315 | 1.00 | 475 | 0.55 |
| 160 | 2.60 | 320 | 1.00 | | |

TABLE C-30. COMPUTER PROGRAM 'TEMP'.

```
10 INPUT "KEEP ALL DATA THE SAME? (Y/N) <ENTER>";Y$
20 ON ASC(Y$)-77 GOTO 40
30 ON ASC(Y$)-88 GOTO 240
40 PRINT "ENTER SAMPLE GAS FLOW RATE IN LITERS PER MIN OR CFM--ENTER 0 "
50 PRINT "FOR THE UNKNOWN VALUE."
60 INPUT "LPM= ,CFM= ",LPM,CFM
70 PRINT "ENTER GAS DENSITY AT AMBIENT;Lb/CuFt;AMBIENT TEMP, DEG F;GAS"
80 PRINT "SAMPLE INLET TEMP, DEG F; GAS SPECIFIC HEAT, Btu/Lb Deg F"
90 INPUT "RHOGAS, T-AMB, T-GASIN, CPGAS",RHOGAS,TAMB,TGASIN,CPGAS
100 PRINT "In LN k=A+B(Ln(TAVGGAS+460)), ENTER A&B FOR THERMAL"
110 PRINT "CONDUCTIVITY OF SAMPLE GAS, OR ENTER 0,0"
120 INPUT "A= ,B= ",A,B
130 PRINT "ENTER TUBING DIAMETERS, Do,Di, INCH; RHOMETAL, Lb/CuFt; SPEC."
140 PRINT "HEAT , Btu/Lb DEG F; MAX TEMP RISE ALLOWED, DEG F"
150 INPUT "Do,Di,RHOMET,CPMET,DELTMAX ",DO,DI,RHOMET,CPMET,DELTMAX
160 PRINT "IN MuGAS=C+DT, DEG F, ENTER C&D, OR ENTER 0,0"
170 INPUT "C= ,D= ",C,D
180 INPUT "GAS SAMPLE DURATION, HOURS= ",TIMEGAS
190 GOTO 320
200 REM Hia is in Btu/Hr Sq Ft Deg F
210 REM TUBESEC is the safe length of tubing for asymptotic gas temp.
220 REM DELTMAX is max allowed temp rise per package of sample gas.
230 REM NUMGAS is number of packages of gas.
240 READ LPM,CFM,RHOGAS,TAMB,TGASIN,CPGAS,A,B,DO,DI,RHOMET,CPMET,DELTMAX,C,D,TIM
EGAS
250 DATA 1.5,0,.07361,80,800,.26,0,0
260 DATA .25,.19,558.1,.0927,10,0,0,.0138889
270 PRINT "CHANGE ANY OR ALL OF THE FOLLOWING BY TYPING DATA1=nn.nn,"
280 PRINT "AND PRESSING <ENTER>, DATA2=nn.nn <ENT>, etc.,and then"
290 PRINT "TYPE {CONT} <ENT>: LPM,CFM,RHOGAS,TAMB,TGASIN,CPGAS,A,B,Do,"
300 PRINT "Di,RHOMET,CPMET,DELTMAX,C,D,TIMEGAS"
310 STOP
320 IF LPM THEN CFM=.0353*LPM
330 TAVGGAS=(TAMB+TGASIN)/2
340 WGAS=CFM*60*RHOGAS
350 IF A=0 THEN A=-9.2423:B=.80594
360 THCON=EXP(A+B*LOG(TAVGGAS+460))
370 PI=3.1415926#
380 CPPERFT=PI*(DO^2-DI^2)*RHOMET*CPMET/576
390 IF C=0 THEN C=.01655:D=.0000206
400 MURATIO=(C+D*TGASIN)/(C+D*TAMB)
410 NGZ=((MURATIO^.14)*PI)^1.5
420 TUBESEG=INT(100*WGAS*CPGAS/(THCON*NGZ))/100
430 HIA=2*WGAS*CPGAS/(DI*PI*TUBESEG)
440 NUMGAS%=WGAS*TIMEGAS*(TGASIN-TAMB)*CPGAS/(CPPERFT*DELTMAX)
450 OPTION BASE 1
460 DIM TUBEWAL(250),GASTEMP(250),GASTOUT(NUMGAS%)
```

TABLE C-30. COMPUTER PROGRAM 'TEMP' (CONCLUDED).

```
470 FOR I=1 TO 100
480 TUBEWAL(I)=TAMB
490 NEXT I
500 FACTOR=TIMEGAS*WGAS*CPGAS/(NUMGAS%*CPPERFT*TUBESEG)
510 FOR N=1 TO NUMGAS%
520 GASTEMP(N)=TGASIN
530 J=1
540 DELT=FACTOR*(GASTEMP(J)-TUBEWAL(J))
550 TUBEWAL(J)=TUBEWAL(J)+DELT
560 GASTEMP(J+1)=TUBEWAL(J)-DELT/2
570 LPRINT J;
580 IF DELT<.01*DELTMAX GOTO 610
590 J=J+1
600 GOTO 540
610 GASTOUT(N)=GASTEMP(J+1)
620 NEXT N
630 GASTSUM=0
640 FOR N=1 TO NUMGAS%
650 GASTSUM=GASTSUM+GASTOUT(N)
660 NEXT N
670 LPRINT "AVG SAMPLE GAS TEMP AT PUMP=";GASTSUM/NUMGAS%
680 LPRINT "LENGTH OF HEATED TUBING, Ft=";J*TUBESEG
690 LPRINT "TEMPERATURE OF HEATED TUBE SEGMENTS, DEG F IS:"
700 FOR M=1 TO J+1
710 LPRINT INT(10*TUBEWAL(M))/10
720 NEXT M
730 LPRINT "CFM=             ,TAVGGAS=       ,wGAS=          ,THCON="
740 LPRINT CFM,TAVGGAS,WGAS,THCON
750 LPRINT
760 LPRINT "CPPERFT=       ,MURATIO=       ,NGZ=           ,TUBESEG="
770 LPRINT CPPERFT,MURATIO,NGZ,TUBESEG
780 LPRINT
790 LPRINT "Hia=           ,NUMGAS%=       ,FACTOR         ,TIMEGAS"
800 LPRINT HIA,NUMGAS%,FACTOR,TIMEGAS
810 LPRINT
820 LPRINT "LPM=           ,CFM=           ,RHOGAS=        ,TAMB=          ,TGASIN="
830 LPRINT LPM,CFM,RHOGAS,TAMB,TGASIN
840 LPRINT
850 LPRINT "CPGAS=         ,A=             ,B=             ,Do=            ,Di="
860 LPRINT CPGAS,A,B,DO,DI
870 LPRINT
880 LPRINT "RHOMET=        ,CPMET=         ,DELTMAX=       ,C=             ,D="
890 LPRINT RHOMET,CPMET,DELTMAX,C,D
900 END
```

TABLE C-31. COMPUTER PROGRAM 'FLOW'.

```
10 DEFDBL B-Z
20 DIM A(101,101), R(101), V(101), X(101), Y(101), F(101), IN$(50),
   T1(101), IPIVOT%(101), T2%(101), INDEX%(101,2), PIVOT(101)
30 PRINT "INPUT THE NUMBER OF FILES TO BE SEQUENTIALLY READ IN"
40 INPUT NUMFILES%
50 PRINT "INPUT THE NAMES OF THE FILES TO BE READ IN"
60 FOR I% = 1 TO NUMFILES%
70 INPUT IN$(I%)
80 NEXT I%
90 PRINT:PRINT "NAMES OF THE OUTPUT FILES ARE THE SAME AS THE INPUT FILES + 'OUT
'"
100 FILECOUNT% = 0
110 PRINT:PRINT "INPUT THE NUMBER OF DATA POINTS (MAXIMUM = 100)
120 INPUT PP%
130 FILECOUNT%=FILECOUNT% + 1
140 IF FILECOUNT% > NUMFILES% THEN 680
150 OPEN "I", #1, IN$(FILECOUNT%)
160 PRINT:PRINT "CONCENTRATION DATA BEING READ"
170 GOSUB 1440
180 PRINT:PRINT "SOLVE FOR VELOCITIES IN UNITS OF VMAX"
190 'VM = MAXIMUM VELOCITY IN FEET/SECOND
200 VM = 8.953026
210 'L = LENGTH OF PIPE IN FEET
220 L = 50
230 'TM IS THE MINIMUM TRANSIT TIME
240 TM = L/VM
250 TT = TM - 2.5
260 'SOLVE FOR THE AVERAGE SECTOR TIMES AND AVERAGE VELOCITIES
270 FOR J%= 1 TO P%
280 T1(J%) = TT + 5*J%
290 V(J%) = L/T1(J%)
300 V(J%) = V(J%)/VM
310 PRINT V(J%)
320 NEXT
330 PRINT:PRINT "SOLVE FOR THE RADII
340 R(0) = 0
350 FOR J% = 1 TO P%
360 B = 2*(1-V(J%))
370 C = (R(J%-1)*R(J%-1))*((R(J%-1)*R(J%-1)) - (2 - 2*V(J%)))
380 RR = (B/2) + (B*B + 4*C)/2
390 R(J%) = SQR(RR)
400 PRINT R(J%)
410 NEXT
420 PRINT:PRINT "SOLVE FOR THE FRACTIONS OF MATERIAL IN EACH SECTION
430 FOR J%=1 TO P%
440 F(J%) = R(J%)*R(J%) - R(J%-1)*R(J%-1)
450 PRINT F(J%)
```

TABLE C-31. COMPUTER PROGRAM 'FLOW' (CONTINUED).

```
460 NEXT
470 PRINT:PRINT "CALCULATE HALON CONCENTRATIONS, Y(I%), AT SOURCE
480 PRINT:PRINT "CALCULATE COEFFICIENTS OF MATRIX"
490 FOR I% = 1 TO P%
500 N%=I%
510 FOR J%=1 TO N%
520 A(I%,J%) = 2*F(N%-J%+1)*V(N%-J%+1)
530 NEXT J%
540 NEXT I%
550 GOSUB 690
560 GOSUB 1340
570 OU$ = IN$(FILECOUNT%) + "OUT"
580 OPEN "O", #1, OU$
590 FOR I% = 1 TO P%
600 PRINT #1, 5*I%,Y(I%)
610 NEXT I%
620 PRINT #1,-1,-1
630 CLOSE
640 FOR I%=0 TO P%
650 PRINT X(I%),Y(I%)
660 NEXT I%
670 GOTO 130
680 END
690 'SUBROUTINE MATRIX INVERSION
700 PRINT:PRINT "INVERT MATRIX"
710 DETERM=1!
720 FOR J%=1 TO P%
730 IPIVOT%(J%) = 0
740 NEXT J%
750 FOR I% = 1 TO P%
760 PRINT I%
770 'SEARCH FOR PIVOT ELEMENT
780 AMAX = 0'
790 FOR J% = 1 TO P%
800 IF IPIVOT%(J%)-1=0 THEN 890
810 FOR K% = 1 TO P%
820 IF IPIVOT%(K%)-1 = 0 THEN 880
830 IF IPIVOT%(K%)-1 > 0 THEN 1310
840 IF ABS(AMAX)-ABS(A(J%,K%)) >= 0 THEN 880
850 IROW%=J%
860 ICOLUM%=K%
870 AMAX=A(J%,K%)
880 NEXT K%
890 NEXT J%
900 IF AMAX=0 THEN 1320
910 IPIVOT%(ICOLUM%) = IPIVOT%(ICOLUM%) + 1
920 'INTERCHANGE ROWS TO PUT PIVOT ELEMENT ON DIAGONAL
```

TABLE C-31. COMPUTER PROGRAM 'FLOW' (CONTINUED).

```
930 IF IROW%-ICOLUM% = 0 THEN 1000
940 DETERM=-DETERM
950 FOR L%=1 TO P%
960 SWA = A(IROW%,L%)
970 A(IROW%,L%) = A(ICOLUM%,L%)
980 A(ICOLUM%,L%) = SWA
990 NEXT L%
1000 INDEX%(I%,1) = IROW%
1010 INDEX%(I%,2)=ICOLUM%
1020 PIVOT(I%)=A(ICOLUM%,ICOLUM%)
1030 DETERM = DETERM*PIVOT(I%)
1040 'DIVIDE PIVOT ROW BY PIVOT ELEMENT
1050 A(ICOLUM%,ICOLUM%)=1!
1060 FOR L%=1 TO P%
1070 A(ICOLUM%,L%)=A(ICOLUM%,L%)/PIVOT(I%)
1080 NEXT L%
1090 'REDUCE NONPIVOT ROWS
1100 FOR L1% = 1 TO P%
1110 IF L1%-ICOLUM% = 0 THEN 1170
1120 T = A(L1%,ICOLUM%)
1130 A(L1%,ICOLUM%)=0!
1140 FOR L%=1 TO P%
1150 A(L1%,L%) = A(L1%,L%)-A(ICOLUM%,L%)*T
1160 NEXT L%
1170 NEXT L1%
1180 NEXT I%
1190 'INTERCHANGE COLUMNS
1200 FOR I% = 1 TO P%
1210 L% = P% + 1 - I%
1220 IF INDEX%(L%,1)-INDEX%(L%,2) = 0 THEN 1300
1230 JROW% = INDEX%(L%,1)
1240 JCOLUM% = INDEX%(L%,2)
1250 FOR K% = 1 TO P%
1260 SWA = A(K%,JROW%)
1270 A(K%,JROW%)=A(K%,JCOLUM%)
1280 A(K%,JCOLUM%)=SWA
1290 NEXT K%
1300 NEXT I%
1310 RETURN
1320 DETERM = 0
1330 RETURN
1340 'SUBROUTINE MATRIX MULTIPLICATION
1350 PRINT:PRINT "MULTIPLY MATRIX"
1360 FOR I% = 1 TO P%
1370 SUM = 0!
1380 FOR J%= 1 TO P%
1390 SUM = SUM + A(I%,J%)*X(J%)
```

TABLE C-31. COMPUTER PROGRAM 'FLOW' (CONCLUDED).

```
1400 NEXT J%
1410 Y(I%) = SUM
1420 NEXT I%
1430 RETURN
1440 'INPUT THE TIMES AND THE CONCENTRATIONS, X(I%), MEASURED BY PERCO
1450 P%=PP%
1460 FOR K% = 1 TO P%
1470 INPUT #1, I%
1480 IF I%<0 THEN P%=K%-1
1490 IF I%<0 THEN 1540
1500 INPUT #1, X(K%)
1510 T2%(K%)=I%
1520 PRINT I%,X(K%)
1530 NEXT K%
1540 CLOSE
1550 RETURN
1560 END
```

TABLE C-32. CORRECTED HALON CONCENTRATION DATA, PROBE H1, TEST 1, SERIES A.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 25 | 0.00 | 110 | 6.15 | 195 | 2.62 |
| 30 | 0.18 | 115 | 5.90 | 200 | 2.70 |
| 35 | 1.27 | 120 | 5.85 | 205 | 2.46 |
| 40 | 3.63 | 125 | 5.89 | 210 | 2.13 |
| 45 | 5.29 | 130 | 5.81 | 215 | 2.02 |
| 50 | 5.36 | 135 | 5.18 | 220 | 1.99 |
| 55 | 5.42 | 140 | 4.33 | 225 | 2.12 |
| 60 | 5.74 | 145 | 4.13 | 230 | 1.95 |
| 65 | 6.16 | 150 | 4.46 | 235 | 1.96 |
| 70 | 6.40 | 155 | 4.31 | 240 | 1.80 |
| 75 | 6.64 | 160 | 3.58 | 245 | 1.55 |
| 80 | 6.73 | 165 | 3.23 | 250 | 1.33 |
| 85 | 6.74 | 170 | 3.27 | 255 | 1.57 |
| 90 | 6.69 | 175 | 3.61 | 260 | 1.59 |
| 95 | 6.67 | 180 | 3.42 | 265 | 1.58 |
| 100 | 6.38 | 185 | 3.24 | 270 | 1.49 |
| 105 | 6.30 | 190 | 2.82 | 275 | 1.32 |

TABLE C-33. CORRECTED HALON CONCENTRATION DATA, PROBE H2, TEST 1, SERIES A.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 25 | 0.00 | 110 | 7.19 | 195 | 6.83 |
| 30 | 1.11 | 115 | 7.19 | 200 | 6.36 |
| 35 | 4.04 | 120 | 7.00 | 205 | 5.66 |
| 40 | 6.38 | 125 | 7.01 | 210 | 5.51 |
| 45 | 6.59 | 130 | 7.03 | 215 | 4.97 |
| 50 | 6.36 | 135 | 6.75 | 220 | 5.17 |
| 55 | 6.47 | 140 | 6.69 | 225 | 5.06 |
| 60 | 6.46 | 145 | 6.91 | 230 | 4.80 |
| 65 | 6.66 | 150 | 7.00 | 235 | 5.04 |
| 70 | 6.97 | 155 | 6.97 | 240 | 4.60 |
| 75 | 7.06 | 160 | 6.87 | 245 | 4.27 |
| 80 | 7.08 | 165 | 6.78 | 250 | 4.36 |
| 85 | 7.22 | 170 | 6.80 | 255 | 4.41 |
| 90 | 7.27 | 175 | 6.81 | 260 | 3.95 |
| 95 | 7.23 | 180 | 6.81 | 265 | 3.27 |
| 100 | 7.21 | 185 | 6.72 | 270 | 2.75 |
| 105 | 7.20 | 190 | 6.73 | 275 | 2.72 |

TABLE C-34. CORRECTED HALON CONCENTRATION DATA, PROBE H3, TEST 1, SERIES A.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 25 | 0.00 | 110 | 5.66 | 195 | 2.16 |
| 30 | 0.74 | 115 | 5.91 | 200 | 1.88 |
| 35 | 3.43 | 120 | 6.10 | 205 | 1.98 |
| 40 | 5.01 | 125 | 6.07 | 210 | 2.31 |
| 45 | 5.52 | 130 | 6.06 | 215 | 2.29 |
| 50 | 5.64 | 135 | 5.87 | 220 | 2.18 |
| 55 | 6.18 | 140 | 4.87 | 225 | 1.91 |
| 60 | 6.75 | 145 | 3.89 | 230 | 1.86 |
| 65 | 7.11 | 150 | 3.56 | 235 | 1.81 |
| 70 | 7.13 | 155 | 3.46 | 240 | 1.74 |
| 75 | 7.02 | 160 | 3.29 | 245 | 1.77 |
| 80 | 6.88 | 165 | 3.93 | 250 | 1.69 |
| 85 | 6.87 | 170 | 3.82 | 255 | 1.43 |
| 90 | 6.87 | 175 | 3.23 | 260 | 1.28 |
| 95 | 6.76 | 180 | 2.94 | 265 | 1.43 |
| 100 | 6.12 | 185 | 2.76 | 270 | 1.54 |
| 105 | 5.73 | 190 | 2.56 | 275 | 1.62 |

TABLE C-35. CORRECTED HALON CONCENTRATION DATA, PROBE H4, TEST 1, SERIES A.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 25 | 0.00 | 110 | 7.39 | 195 | 4.89 |
| 30 | 1.85 | 115 | 7.39 | 200 | 4.49 |
| 35 | 4.33 | 120 | 7.39 | 205 | 5.68 |
| 40 | 5.25 | 125 | 7.29 | 210 | 6.41 |
| 45 | 5.73 | 130 | 7.30 | 215 | 6.54 |
| 50 | 6.09 | 135 | 7.31 | 220 | 6.35 |
| 55 | 6.52 | 140 | 7.31 | 225 | 6.14 |
| 60 | 6.99 | 145 | 7.21 | 230 | 6.25 |
| 65 | 7.56 | 150 | 7.13 | 235 | 6.26 |
| 70 | 7.66 | 155 | 7.06 | 240 | 5.42 |
| 75 | 7.62 | 160 | 7.17 | 245 | 5.14 |
| 80 | 7.46 | 165 | 7.26 | 250 | 5.26 |
| 85 | 7.44 | 170 | 7.24 | 255 | 5.13 |
| 90 | 7.52 | 175 | 7.23 | 260 | 4.51 |
| 95 | 7.50 | 180 | 7.23 | 265 | 4.23 |
| 100 | 7.48 | 185 | 7.23 | 270 | 4.53 |
| 105 | 7.38 | 190 | 6.68 | 275 | 4.56 |

TABLE C-36. CORRECTED HALON CONCENTRATION DATA, PROBE H5, TEST 1, SERIES A.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 25 | 0.00 | 110 | 5.68 | 195 | 2.46 |
| 30 | 0.46 | 115 | 5.60 | 200 | 2.33 |
| 35 | 1.89 | 120 | 5.53 | 205 | 2.28 |
| 40 | 3.72 | 125 | 5.28 | 210 | 2.22 |
| 45 | 5.01 | 130 | 4.95 | 215 | 2.16 |
| 50 | 5.90 | 135 | 5.11 | 220 | 2.09 |
| 55 | 6.39 | 140 | 5.23 | 225 | 1.93 |
| 60 | 6.49 | 145 | 4.94 | 230 | 1.96 |
| 65 | 6.41 | 150 | 4.13 | 235 | 1.90 |
| 70 | 6.14 | 155 | 3.51 | 240 | 1.91 |
| 75 | 5.75 | 160 | 3.31 | 245 | 1.83 |
| 80 | 5.69 | 165 | 3.16 | 250 | 1.66 |
| 85 | 5.73 | 170 | 3.06 | 255 | 1.60 |
| [illegible] | 5.82 | 175 | 2.93 | 260 | 1.36 |
| 95 | 5.81 | 180 | 2.89 | 265 | 1.21 |
| 100 | 5.89 | 185 | 2.75 | 270 | 1.17 |
| 105 | 5.88 | 190 | 2.60 | 275 | [illegible] |

TABLE C-37. CORRECTED HALON CONCENTRATION DATA, PROBE H6, TEST 1, SERIES A.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 25 | 0.00 | 110 | 7.19 | 195 | 6.73 |
| 30 | 2.95 | 115 | 7.18 | 200 | 6.67 |
| 35 | 5.79 | 120 | 7.18 | 205 | [illegible] |
| 40 | 6.72 | 125 | 7.17 | 210 | [illegible] |
| 45 | 6.57 | 130 | 7.17 | 215 | 6.48 |
| 50 | 6.95 | 135 | 7.17 | 220 | 6.59 |
| 55 | 7.53 | 140 | 7.26 | 225 | 6.79 |
| 60 | 7.80 | 145 | 7.25 | 230 | 6.30 |
| 65 | 7.73 | 150 | 7.24 | 235 | 6.05 |
| 70 | 7.55 | 155 | 7.05 | 240 | 5.48 |
| 75 | 7.25 | 160 | 7.07 | 245 | 4.47 |
| 80 | 7.17 | 165 | 7.09 | 250 | 3.64 |
| 85 | 7.19 | 170 | 7.09 | 255 | 3.05 |
| 90 | 7.20 | 175 | 7.09 | 260 | 2.71 |
| 95 | 7.16 | 180 | 7.09 | 265 | 2.41 |
| 100 | 7.10 | 185 | 7.09 | 270 | 2.10 |
| 105 | 7.20 | 190 | [illegible] | 275 | [illegible] |

TABLE C-38. CORRECTED HALON CONCENTRATION DATA, PROBE H1, TEST 2, SERIES A.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 25 | 0.00 | 110 | 3.27 | 195 | 0.39 |
| 30 | 0.28 | 115 | 2.74 | 200 | 0.34 |
| 35 | 0.89 | 120 | 2.50 | 205 | 0.28 |
| 40 | 2.37 | 125 | 2.43 | 210 | 0.31 |
| 45 | 4.26 | 130 | 2.41 | 215 | 0.23 |
| 50 | 5.80 | 135 | 2.27 | 220 | 0.15 |
| 55 | 5.54 | 140 | 1.94 | 225 | 0.18 |
| 60 | 4.63 | 145 | 1.54 | 230 | 0.19 |
| 65 | 4.82 | 150 | 1.36 | 235 | 0.19 |
| 70 | 4.83 | 155 | 1.26 | 240 | 0.20 |
| 75 | 4.05 | 160 | 1.04 | 245 | 0.20 |
| 80 | 3.84 | 165 | 1.01 | 250 | 0.20 |
| 85 | 3.94 | 170 | 0.97 | 255 | 0.20 |
| 90 | 4.43 | 175 | 0.90 | 260 | 0.20 |
| 95 | 4.38 | 180 | 0.84 | 265 | 0.20 |
| 100 | 4.43 | 185 | 0.68 | 270 | 0.20 |
| 105 | 3.77 | 190 | 0.53 | 275 | 0.20 |

TABLE C-39. CORRECTED HALON CONCENTRATION DATA, PROBE H2, TEST 2, SERIES A.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 25 | 0.00 | 110 | 1.00 | 195 | 0.37 |
| 30 | 0.18 | 115 | 1.10 | 200 | 0.39 |
| 35 | 1.00 | 120 | 1.19 | 205 | 0.31 |
| 40 | 3.20 | 125 | 1.27 | 210 | 0.32 |
| 45 | 5.36 | 130 | 1.35 | 215 | 0.33 |
| 50 | 7.07 | 135 | 1.33 | 220 | 0.25 |
| 55 | 5.90 | 140 | 1.32 | 225 | 0.26 |
| 60 | 5.04 | 145 | 1.23 | 230 | 0.27 |
| 65 | 3.45 | 150 | 1.05 | 235 | 0.27 |
| 70 | 2.64 | 155 | 0.99 | 240 | 0.27 |
| 75 | 2.17 | 160 | 0.74 | 245 | 0.27 |
| 80 | 1.71 | 165 | 0.60 | 250 | 0.27 |
| 85 | 1.32 | 170 | 0.56 | 255 | 0.18 |
| 90 | 1.18 | 175 | 0.50 | 260 | 0.19 |
| 95 | 1.20 | 180 | 0.52 | 265 | 0.20 |
| 100 | 0.89 | 185 | 0.54 | 270 | 0.20 |
| 105 | 0.95 | 190 | 0.45 | 275 | 0.11 |

TABLE C-40. CORRECTED HALON CONCENTRATION DATA, PROBE H3, TEST 2, SERIES A.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 25 | 0.00 | 110 | 3.44 | 195 | 1.05 |
| 30 | 1.57 | 115 | 3.25 | 200 | 0.89 |
| 35 | 4.55 | 120 | 2.95 | 205 | 0.92 |
| 40 | 7.29 | 125 | 2.66 | 210 | 0.86 |
| 45 | 8.36 | 130 | 2.48 | 215 | 0.87 |
| 50 | 8.07 | 135 | 2.37 | 220 | 0.88 |
| 55 | 6.87 | 140 | 2.15 | 225 | 0.80 |
| 60 | 5.94 | 145 | 2.03 | 230 | 0.62 |
| 65 | 5.16 | 150 | 1.81 | 235 | 0.56 |
| 70 | 5.15 | 155 | 1.68 | 240 | 0.50 |
| 75 | 5.63 | 160 | 1.46 | 245 | 0.52 |
| 80 | 5.71 | 165 | 1.34 | 250 | 0.54 |
| 85 | 5.57 | 170 | 1.30 | 255 | 0.54 |
| 90 | 5.02 | 175 | 1.25 | 260 | 0.64 |
| 95 | 4.44 | 180 | 1.18 | 265 | 0.54 |
| 100 | 3.91 | 185 | 1.21 | 270 | 0.54 |
| 105 | 3.59 | 190 | 1.13 | 275 | 0.55 |

TABLE C-41. CORRECTED HALON CONCENTRATION DATA, PROBE H4, TEST 2, SERIES A.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 25 | 0.00 | 110 | 2.46 | 195 | 0.47 |
| 30 | 0.37 | 115 | 2.02 | 200 | 0.41 |
| 35 | 0.52 | 120 | 1.71 | 205 | 0.45 |
| 40 | 4.34 | 125 | 1.73 | 210 | 0.37 |
| 45 | 7.61 | 130 | 1.81 | 215 | 0.38 |
| 50 | 8.29 | 135 | 1.74 | 220 | 0.40 |
| 55 | 7.42 | 140 | 1.58 | 225 | 0.31 |
| 60 | 5.56 | 145 | 1.34 | 230 | 0.32 |
| 65 | 4.96 | 150 | 1.30 | 235 | 0.33 |
| 70 | 5.07 | 155 | 1.25 | 240 | 0.34 |
| 75 | 3.95 | 160 | 1.28 | 245 | 0.34 |
| 80 | 3.44 | 165 | 1.20 | 250 | 0.34 |
| 85 | 3.54 | 170 | 1.12 | 255 | 0.34 |
| 90 | 4.00 | 175 | 0.96 | 260 | 0.34 |
| 95 | 3.80 | 180 | 0.81 | 265 | 0.34 |
| 100 | 3.42 | 185 | 0.67 | 270 | 0.34 |
| 105 | 3.12 | 190 | 0.62 | 275 | 0.34 |

TABLE C-42. CORRECTED HALON CONCENTRATION DATA, PROBE H5, TEST 2, SERIES A.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 25 | 0.00 | 110 | 0.91 | 195 | 0.31 |
| 30 | 0.46 | 115 | 1.21 | 200 | 0.33 |
| 35 | 2.54 | 120 | 1.38 | 205 | 0.24 |
| 40 | 5.22 | 125 | 1.34 | 210 | 0.25 |
| 45 | 7.64 | 130 | 1.13 | 215 | 0.17 |
| 50 | 8.20 | 135 | 1.06 | 220 | 0.28 |
| 55 | 6.05 | 140 | 1.18 | 225 | 0.19 |
| 60 | 4.00 | 145 | 1.00 | 230 | 0.19 |
| 65 | 2.39 | 150 | 0.92 | 235 | 0.20 |
| 70 | 1.76 | 155 | 0.76 | 240 | 0.20 |
| 75 | 1.43 | 160 | 0.61 | 245 | 0.20 |
| 80 | 1.45 | 165 | 0.56 | 250 | 0.20 |
| 85 | 1.84 | 170 | 0.50 | 255 | 0.20 |
| 90 | 1.76 | 175 | 0.52 | 260 | 0.11 |
| 95 | 1.21 | 180 | 0.45 | 265 | 0.12 |
| 100 | 0.82 | 185 | 0.46 | 270 | 0.13 |
| 105 | 0.84 | 190 | 0.29 | 275 | 0.23 |

TABLE C-43. CORRECTED HALON CONCENTRATION DATA, PROBE H6, TEST 2, SERIES A.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 25 | 0.00 | 110 | 2.78 | 195 | 0.51 |
| 30 | 1.20 | 115 | 2.31 | 200 | 0.53 |
| 35 | 4.31 | 120 | 1.81 | 205 | 0.53 |
| 40 | 7.08 | 125 | 1.76 | 210 | 0.54 |
| 45 | 8.24 | 130 | 1.58 | 215 | 0.54 |
| 50 | 8.12 | 135 | 1.46 | 220 | 0.45 |
| 55 | 7.08 | 140 | 1.43 | 225 | 0.46 |
| 60 | 5.93 | 145 | 1.38 | 230 | 0.47 |
| 65 | 4.96 | 150 | 1.32 | 235 | 0.48 |
| 70 | 4.52 | 155 | 1.25 | 240 | 0.39 |
| 75 | 4.15 | 160 | 1.19 | 245 | 0.40 |
| 80 | 3.91 | 165 | 1.03 | 250 | 0.41 |
| 85 | 4.30 | 170 | 0.97 | 255 | 0.32 |
| 90 | 3.77 | 175 | 0.82 | 260 | 0.33 |
| 95 | 2.97 | 180 | 0.67 | 265 | 0.34 |
| 100 | 3.58 | 185 | 0.53 | 270 | 0.34 |
| 105 | 3.54 | 190 | 0.48 | 275 | 0.43 |

TABLE C-44. CORRECTED HALON CONCENTRATION DATA, PROBE H1, TEST 1, SERIES B.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 25 | 0.00 | 110 | 5.56 | 195 | 3.44 |
| 30 | 0.28 | 115 | 5.74 | 200 | 2.08 |
| 35 | 0.80 | 120 | 5.94 | 205 | 2.32 |
| 40 | 1.27 | 125 | 6.14 | 210 | 3.00 |
| 45 | 1.80 | 130 | 6.44 | 215 | 2.92 |
| 50 | 2.31 | 135 | 6.73 | 220 | 2.45 |
| 55 | 2.63 | 140 | 6.92 | 225 | 1.97 |
| 60 | 3.05 | 145 | 7.02 | 230 | 1.72 |
| 65 | 3.48 | 150 | 7.05 | 235 | 1.18 |
| 70 | 3.90 | 155 | 6.83 | 240 | 1.02 |
| 75 | 3.95 | 160 | 6.64 | 245 | 0.86 |
| 80 | 3.95 | 165 | 6.58 | 250 | 0.66 |
| 85 | 4.18 | 170 | 6.51 | 255 | 0.55 |
| 90 | 4.31 | 175 | 6.53 | 260 | 0.42 |
| 95 | 4.62 | 180 | 6.45 | 265 | 0.29 |
| 100 | 4.92 | 185 | 6.18 | 270 | 0.25 |
| 105 | 5.29 | 190 | 5.66 | 275 | 0.19 |

TABLE C-45. CORRECTED HALON CONCENTRATION DATA, PROBE H2, TEST 1, SERIES B.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 25 | 0.00 | 110 | 8.42 | 195 | 9.31 |
| 30 | 0.55 | 115 | 8.58 | 200 | 9.35 |
| 35 | 1.88 | 120 | 9.09 | 205 | 9.47 |
| 40 | 3.34 | 125 | 9.38 | 210 | 9.09 |
| 45 | 5.05 | 130 | 9.64 | 215 | 8.84 |
| 50 | 6.95 | 135 | 9.92 | 220 | 8.82 |
| 55 | 8.96 | 140 | 10.02 | 225 | 8.68 |
| 60 | 9.99 | 145 | 9.86 | 230 | 8.53 |
| 65 | 10.52 | 150 | 9.65 | 235 | 8.57 |
| 70 | 10.56 | 155 | 9.48 | 240 | 6.75 |
| 75 | 10.16 | 160 | 9.51 | 245 | 5.84 |
| 80 | 9.17 | 165 | 9.62 | 250 | 3.56 |
| 85 | 7.95 | 170 | 9.61 | 255 | 2.12 |
| 90 | 7.32 | 175 | 9.51 | 260 | 1.51 |
| 95 | 7.81 | 180 | 9.61 | 265 | 1.31 |
| 100 | 8.24 | 185 | 9.70 | 270 | 1.07 |
| 105 | 8.28 | 190 | 9.59 | 275 | 1.04 |

TABLE C-46. CORRECTED HALON CONCENTRATION DATA, PROBE H3, TEST 1, SERIES B.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 25 | 0.00 | 105 | 8.05 | 185 | 4.99 |
| 30 | 0.37 | 110 | 8.00 | 190 | 4.85 |
| 35 | 1.44 | 115 | 7.79 | 195 | 4.70 |
| 40 | 3.32 | 120 | 7.43 | 200 | 4.46 |
| 45 | 5.02 | 125 | 7.11 | 205 | 4.33 |
| 50 | 5.87 | 130 | 7.00 | 210 | 4.11 |
| 55 | 6.78 | 135 | 6.78 | 215 | 3.98 |
| 60 | 7.02 | 140 | 6.19 | 220 | 3.95 |
| 65 | 6.88 | 145 | 5.73 | 225 | 3.98 |
| 70 | 7.04 | 150 | 5.40 | 230 | 2.15 |
| 75 | 7.15 | 155 | 5.43 | 235 | 2.07 |
| 80 | 7.17 | 160 | 5.87 | 240 | 1.29 |
| 85 | 7.76 | 165 | 5.76 | 245 | 1.35 |
| 90 | 7.85 | 170 | 5.37 | 250 | 0.66 |
| 95 | 7.75 | 175 | 5.15 | 255 | -0.33 |
| 100 | 7.90 | 180 | 5.03 | | |

TABLE C-47. CORRECTED HALON CONCENTRATION DATA, PROBE H4, TEST 1, SERIES B.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 25 | 0.00 | 110 | 9.63 | 195 | 8.87 |
| 30 | 0.18 | 115 | 9.72 | 200 | 8.89 |
| 35 | 0.53 | 120 | 9.72 | 205 | 8.52 |
| 40 | 1.77 | 125 | 9.52 | 210 | 8.10 |
| 45 | 2.70 | 130 | 9.53 | 215 | 8.19 |
| 50 | 5.96 | 135 | 9.27 | 220 | 8.52 |
| 55 | 8.04 | 140 | 9.20 | 225 | 8.68 |
| 60 | 8.86 | 145 | 9.24 | 230 | 8.27 |
| 65 | 8.56 | 150 | 9.25 | 235 | 8.10 |
| 70 | 9.25 | 155 | 9.25 | 240 | 3.17 |
| 75 | 9.44 | 160 | 9.25 | 245 | 3.15 |
| 80 | 9.35 | 165 | 9.25 | 250 | 2.45 |
| 85 | 9.35 | 170 | 9.16 | 255 | 2.14 |
| 90 | 9.49 | 175 | 8.98 | 260 | 1.46 |
| 95 | 9.62 | 180 | 8.82 | 265 | 0.92 |
| 100 | 9.84 | 185 | 9.05 | 270 | 1.13 |
| 105 | 9.87 | 190 | 8.87 | 275 | 0.51 |

TABLE C-48. CORRECTED HALON CONCENTRATION DATA, PROBE H5, TEST 1, SERIES B.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 25 | 0.00 | 110 | 7.81 | 195 | 4.66 |
| 30 | 0.18 | 115 | 7.72 | 200 | 4.54 |
| 35 | 0.81 | 120 | 7.55 | 205 | 4.50 |
| 40 | 2.11 | 125 | 7.48 | 210 | 4.35 |
| 45 | 3.65 | 130 | 7.14 | 215 | 4.21 |
| 50 | 5.07 | 135 | 6.63 | 220 | 3.97 |
| 55 | 6.07 | 140 | 6.17 | 225 | 3.47 |
| 60 | 6.72 | 145 | 5.83 | 230 | 2.46 |
| 65 | 7.26 | 150 | 5.94 | 235 | 2.55 |
| 70 | 7.67 | 155 | 6.00 | 240 | 2.13 |
| 75 | 7.75 | 160 | 5.93 | 245 | 2.22 |
| 80 | 7.80 | 165 | 5.94 | 250 | 2.29 |
| 85 | 7.81 | 170 | 5.87 | 255 | 1.39 |
| 90 | 7.85 | 175 | 5.60 | 260 | 0.38 |
| 95 | 7.81 | 180 | 5.28 | 265 | 0.42 |
| 100 | 7.97 | 185 | 5.07 | 270 | 0.30 |
| 105 | 7.93 | 190 | 4.77 | 275 | 0.18 |

TABLE C-49. CORRECTED HALON CONCENTRATION DATA, PROBE H6, TEST 1, SERIES B

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 25 | 0.00 | 110 | 10.44 | 195 | 9.21 |
| 30 | 0.83 | 115 | 10.42 | 200 | 9.08 |
| 35 | 2.04 | 120 | 10.40 | 205 | 8.76 |
| 40 | 3.11 | 125 | 10.49 | 210 | 8.45 |
| 45 | 4.31 | 130 | 10.47 | 215 | 8.35 |
| 50 | 6.03 | 135 | 10.46 | 220 | 8.51 |
| 55 | 7.76 | 140 | 10.18 | 225 | 8.53 |
| 60 | 8.86 | 145 | 10.02 | 230 | 5.29 |
| 65 | 9.54 | 150 | 9.97 | 235 | 4.62 |
| 70 | 9.85 | 155 | 10.09 | 240 | 4.23 |
| 75 | 9.88 | 160 | 10.00 | 245 | 3.45 |
| 80 | 10.01 | 165 | 9.72 | 250 | 2.20 |
| 85 | 10.19 | 170 | 9.85 | 255 | 1.48 |
| 90 | 10.38 | 175 | 9.97 | 260 | 1.13 |
| 95 | 10.39 | 180 | 9.86 | 265 | 0.97 |
| 100 | 10.42 | 185 | 9.67 | 270 | 0.75 |
| 105 | 10.47 | 190 | 9.33 | 275 | 0.58 |

TABLE C-50. CORRECTED HALON CONCENTRATION DATA, PROBE H1, TEST 2, SERIES B.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 25 | 0.00 | 65 | 2.08 | 105 | 0.53 |
| 30 | 0.18 | 70 | 3.82 | 110 | 0.43 |
| 35 | 0.44 | 75 | 3.25 | 115 | 0.21 |
| 40 | 0.86 | 80 | 2.36 | 120 | 0.18 |
| 45 | 1.33 | 85 | 1.80 | 125 | 0.14 |
| 50 | 1.87 | 90 | 1.38 | 130 | 0.16 |
| 55 | 2.29 | 95 | 0.95 | | |
| 60 | 2.15 | 100 | 0.70 | | |

TABLE C-51. CORRECTED HALON CONCENTRATION DATA, PROBE H2, TEST 2, SERIES B.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 25 | 0.00 | 65 | 7.06 | 105 | 0.35 |
| 30 | 0.46 | 70 | 5.29 | 110 | 0.25 |
| 35 | 1.34 | 75 | 5.20 | 115 | 0.13 |
| 40 | 3.41 | 80 | 2.90 | 120 | 0.19 |
| 45 | 5.85 | 85 | 1.43 | 125 | 0.22 |
| 50 | 7.53 | 90 | 0.78 | 130 | 0.23 |
| 55 | 7.99 | 95 | 0.55 | 135 | 0.24 |
| 60 | 7.60 | 100 | 0.39 | | |

TABLE C-52. CORRECTED HALON CONCENTRATION DATA, PROBE H3, TEST 2, SERIES B.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 25 | 0.00 | 60 | 7.02 | 95 | 2.16 |
| 30 | 0.46 | 65 | 5.62 | 100 | 1.10 |
| 35 | 2.08 | 70 | 5.32 | 105 | 0.53 |
| 40 | 3.43 | 75 | 5.65 | 110 | 0.30 |
| 45 | 5.30 | 80 | 5.31 | 115 | 0.18 |
| 50 | 7.65 | 85 | 3.57 | 120 | 0.10 |
| 55 | 8.21 | 90 | 1.76 | 125 | -0.01 |

TABLE C-53. CORRECTED HALON CONCENTRATION DATA, PROBE H4, TEST 2, SERIES B.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 25 | 0.00 | 65 | 7.55 | 105 | 0.94 |
| 30 | 0.28 | 70 | 6.23 | 110 | 0.59 |
| 35 | 2.37 | 75 | 6.31 | 115 | 0.31 |
| 40 | 4.16 | 80 | 7.01 | 120 | 0.21 |
| 45 | 6.12 | 85 | 5.87 | 125 | 0.15 |
| 50 | 8.12 | 90 | 3.99 | 130 | 0.13 |
| 55 | 9.70 | 95 | 3.93 | 135 | 0.18 |
| 60 | 9.44 | 100 | 2.15 | 140 | 0.21 |

TABLE C-54. CORRECTED HALON CONCENTRATION DATA, PROBE H5, TEST 2, SERIES B.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 25 | 0.00 | 65 | 3.92 | 105 | 0.70 |
| 30 | 0.28 | 70 | 4.23 | 110 | 0.48 |
| 35 | 0.43 | 75 | 3.56 | 115 | 0.40 |
| 40 | 1.03 | 80 | 2.25 | 120 | 0.29 |
| 45 | 1.87 | 85 | 2.06 | 125 | 0.25 |
| 50 | 2.62 | 90 | 2.68 | 130 | 0.20 |
| 55 | 3.06 | 95 | 1.76 | 135 | 0.05 |
| 60 | 3.62 | 100 | 1.08 | 140 | -0.01 |

TABLE C-55. CORRECTED HALON CONCENTRATION DATA, PROBE H6, TEST 2, SERIES B.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 25 | 0.00 | 65 | 4.30 | 105 | 0.47 |
| 30 | 0.37 | 70 | 4.01 | 110 | 0.36 |
| 35 | 0.79 | 75 | 2.60 | 115 | 0.32 |
| 40 | 1.72 | 80 | 2.01 | 120 | 0.27 |
| 45 | 2.58 | 85 | 1.78 | 125 | 0.30 |
| 50 | 3.38 | 90 | 1.08 | 130 | 0.23 |
| 55 | 4.16 | 95 | 0.77 | 135 | 0.24 |
| 60 | 5.31 | 100 | 0.55 | | |

TABLE C-56. CORRECTED HALON CONCENTRATION DATA, PROBE H1, TEST 2, SERIES C.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 25 | 0.00 | 110 | 3.00 | 195 | 1.35 |
| 30 | 0.46 | 115 | 2.85 | 200 | 1.36 |
| 35 | 1.15 | 120 | 2.70 | 205 | 1.28 |
| 40 | 1.77 | 125 | 2.56 | 210 | 1.20 |
| 45 | 2.35 | 130 | 2.42 | 215 | 1.13 |
| 50 | 2.73 | 135 | 2.37 | 220 | 1.06 |
| 55 | 2.95 | 140 | 2.22 | 225 | 1.08 |
| 60 | 3.30 | 145 | 2.16 | 230 | 1.00 |
| 65 | 3.47 | 150 | 2.10 | 235 | 1.02 |
| 70 | 3.56 | 155 | 1.94 | 240 | 1.03 |
| 75 | 3.59 | 160 | 1.88 | 245 | 0.94 |
| 80 | 3.63 | 165 | 1.82 | 250 | 0.86 |
| 85 | 3.60 | 170 | 1.66 | 255 | 0.79 |
| 90 | 3.58 | 175 | 1.60 | 260 | 0.81 |
| 95 | 3.39 | 180 | 1.54 | 265 | 0.73 |
| 100 | 3.22 | 185 | 1.38 | 270 | 0.74 |
| 105 | 3.16 | 190 | 1.41 | 275 | 0.75 |

TABLE C-57. CORRECTED HALON CONCENTRATION DATA, PROBE H2, TEST 2, SERIES C.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 25 | 0.00 | 110 | 6.85 | 195 | 2.84 |
| 30 | 0.46 | 115 | 6.58 | 200 | 2.78 |
| 35 | 2.72 | 120 | 6.11 | 205 | 2.62 |
| 40 | 5.21 | 125 | 6.03 | 210 | 2.47 |
| 45 | 7.07 | 130 | 5.38 | 215 | 2.51 |
| 50 | 8.26 | 135 | 4.84 | 220 | 2.45 |
| 55 | 8.79 | 140 | 4.63 | 225 | 2.46 |
| 60 | 8.90 | 145 | 4.38 | 230 | 2.38 |
| 65 | 9.14 | 150 | 4.01 | 235 | 2.40 |
| 70 | 9.27 | 155 | 3.34 | 240 | 2.23 |
| 75 | 9.15 | 160 | 3.65 | 245 | 2.25 |
| 80 | 9.18 | 165 | 3.54 | 250 | 2.18 |
| 85 | 8.96 | 170 | 3.42 | 255 | 2.10 |
| 90 | 8.30 | 175 | 3.28 | 260 | 1.94 |
| 95 | 7.91 | 180 | 3.15 | 265 | 1.88 |
| 100 | 7.47 | 185 | 2.92 | 270 | 1.82 |
| 105 | 7.11 | 190 | 2.89 | 275 | 1.75 |

TABLE C-58. CORRECTED HALON CONCENTRATION DATA, PROBE H3, TEST 2, SERIES C.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 25 | 0.00 | 110 | 2.42 | 195 | 1.13 |
| 30 | 0.55 | 115 | 2.28 | 200 | 1.16 |
| 35 | 1.24 | 120 | 2.13 | 205 | 1.08 |
| 40 | 2.12 | 125 | 1.99 | 210 | 1.09 |
| 45 | 3.22 | 130 | 1.85 | 215 | 1.10 |
| 50 | 4.17 | 135 | 1.80 | 220 | 1.01 |
| 55 | 4.72 | 140 | 1.75 | 225 | 1.02 |
| 60 | 4.57 | 145 | 1.77 | 230 | 0.94 |
| 65 | 4.26 | 150 | 1.69 | 235 | 0.86 |
| 70 | 3.96 | 155 | 1.52 | 240 | 0.88 |
| 75 | 3.89 | 160 | 1.46 | 245 | 0.89 |
| 80 | 3.92 | 165 | 1.40 | 250 | 0.89 |
| 85 | 3.55 | 170 | 1.34 | 255 | 0.90 |
| 90 | 3.12 | 175 | 1.36 | 260 | 0.90 |
| 95 | 2.84 | 180 | 1.28 | 265 | 0.90 |
| 100 | 2.65 | 185 | 1.29 | 270 | 0.90 |
| 105 | 2.44 | 190 | 1.21 | 275 | 0.90 |

TABLE C 59. CORRECTED HALON CONCENTRATION DATA, PROBE H5, TEST 2, SERIES C

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 25 | 0.00 | 110 | 4.75 | 195 | 2.07 |
| 30 | 0.83 | 115 | 4.60 | 200 | 2.01 |
| 35 | 1.76 | 120 | 4.54 | 205 | 1.95 |
| 40 | 2.49 | 125 | 4.30 | 210 | 1.89 |
| 45 | 3.11 | 130 | 4.06 | 215 | 1.82 |
| 50 | 3.56 | 135 | 3.84 | 220 | 1.66 |
| 55 | 4.03 | 140 | 3.54 | 225 | 1.69 |
| 60 | 4.42 | 145 | 3.33 | 230 | 1.62 |
| 65 | 4.83 | 150 | 3.13 | 235 | 1.64 |
| 70 | 4.87 | 155 | 3.01 | 240 | 1.65 |
| 75 | 5.05 | 160 | 2.98 | 245 | 1.56 |
| 80 | 5.07 | 165 | 2.74 | 250 | 1.48 |
| 85 | 5.20 | 170 | 2.60 | 255 | 1.41 |
| 90 | 5.34 | 175 | 2.47 | 260 | 1.43 |
| 95 | 5.29 | 180 | 2.33 | 265 | 1.35 |
| 100 | 5.08 | 185 | 2.28 | 270 | 1.36 |
| 105 | 4.90 | 190 | 2.23 | 275 | 1.26 |

TABLE C-60. CORRECTED HALON CONCENTRATION DATA, PROBE H6, TEST 2, SERIES C.

| Time, s | Concentration, % by volume | Time, s | Concentration, % by volume | Time, s | Concentration, % by volume |
|---|---|---|---|---|---|
| 25 | 0.00 | 110 | 7.18 | 195 | 3.31 |
| 30 | 0.65 | 115 | 6.83 | 200 | 3.26 |
| 35 | 1.69 | 120 | 6.76 | 205 | 3.11 |
| 40 | 2.80 | 125 | 6.10 | 210 | 2.96 |
| 45 | 4.20 | 130 | 5.46 | 215 | 2.91 |
| 50 | 5.63 | 135 | 4.89 | 220 | 2.67 |
| 55 | 6.63 | 140 | 4.68 | 225 | 2.62 |
| 60 | 7.10 | 145 | 4.63 | 230 | 2.48 |
| 65 | 7.47 | 150 | 4.62 | 235 | 2.33 |
| 70 | 8.01 | 155 | 4.38 | 240 | 2.19 |
| 75 | 8.29 | 160 | 4.25 | 245 | 2.14 |
| 80 | 8.40 | 165 | 4.03 | 250 | 2.09 |
| 85 | 8.57 | 170 | 3.81 | 255 | 2.02 |
| 90 | 8.76 | 175 | 3.70 | 260 | 1.95 |
| 95 | 8.68 | 180 | 3.57 | 265 | 1.98 |
| 100 | 8.17 | 185 | 3.52 | 270 | 1.90 |
| 105 | 7.74 | 190 | 3.47 | 275 | 1.82 |

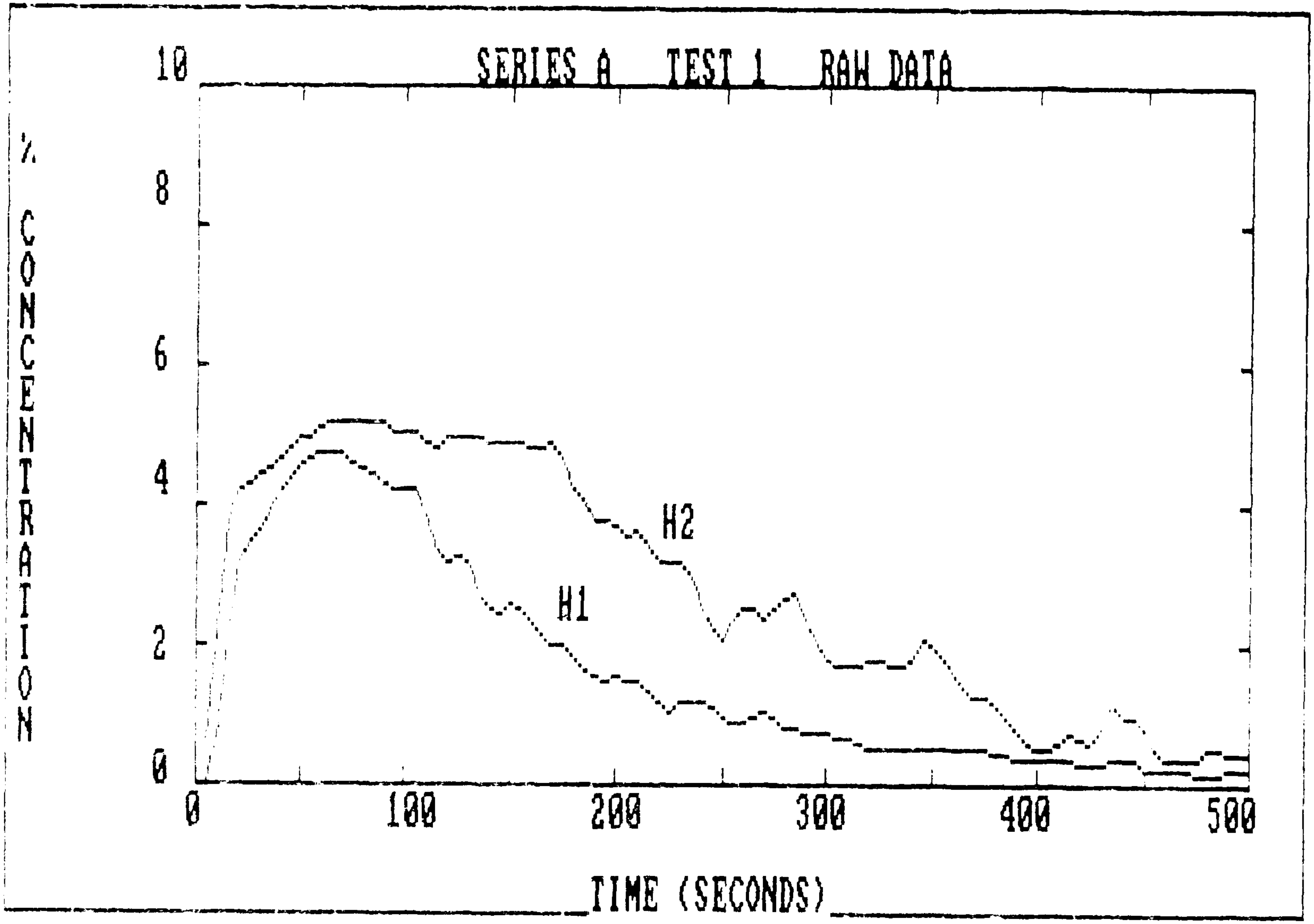



Figure C-1. Raw Halon Concentrations for Series A, Test 1, Probes H1 and H2.

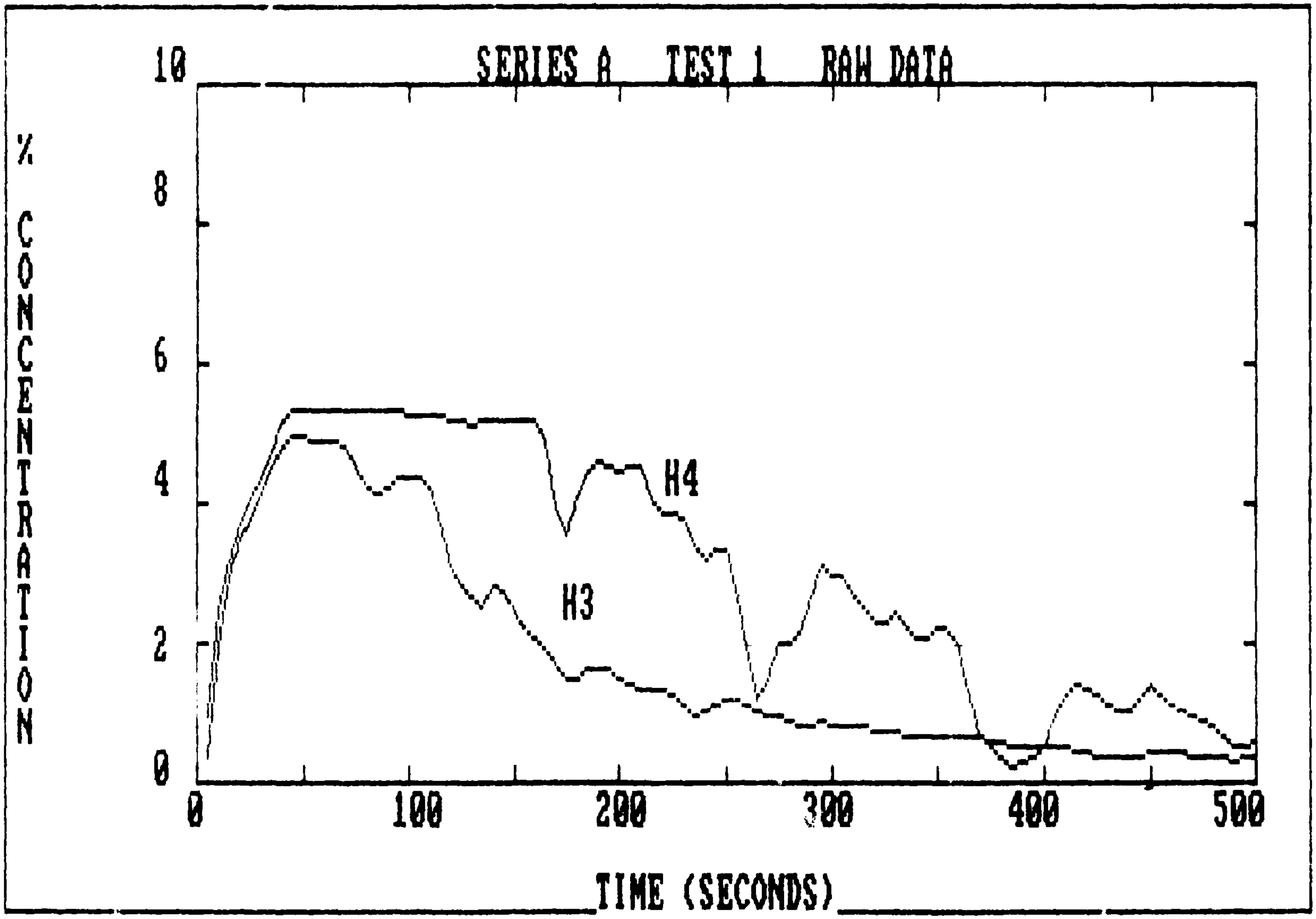



Figure C-2. Raw Halon Concentrations for Series A, Test 1, Probes H3 and H4.

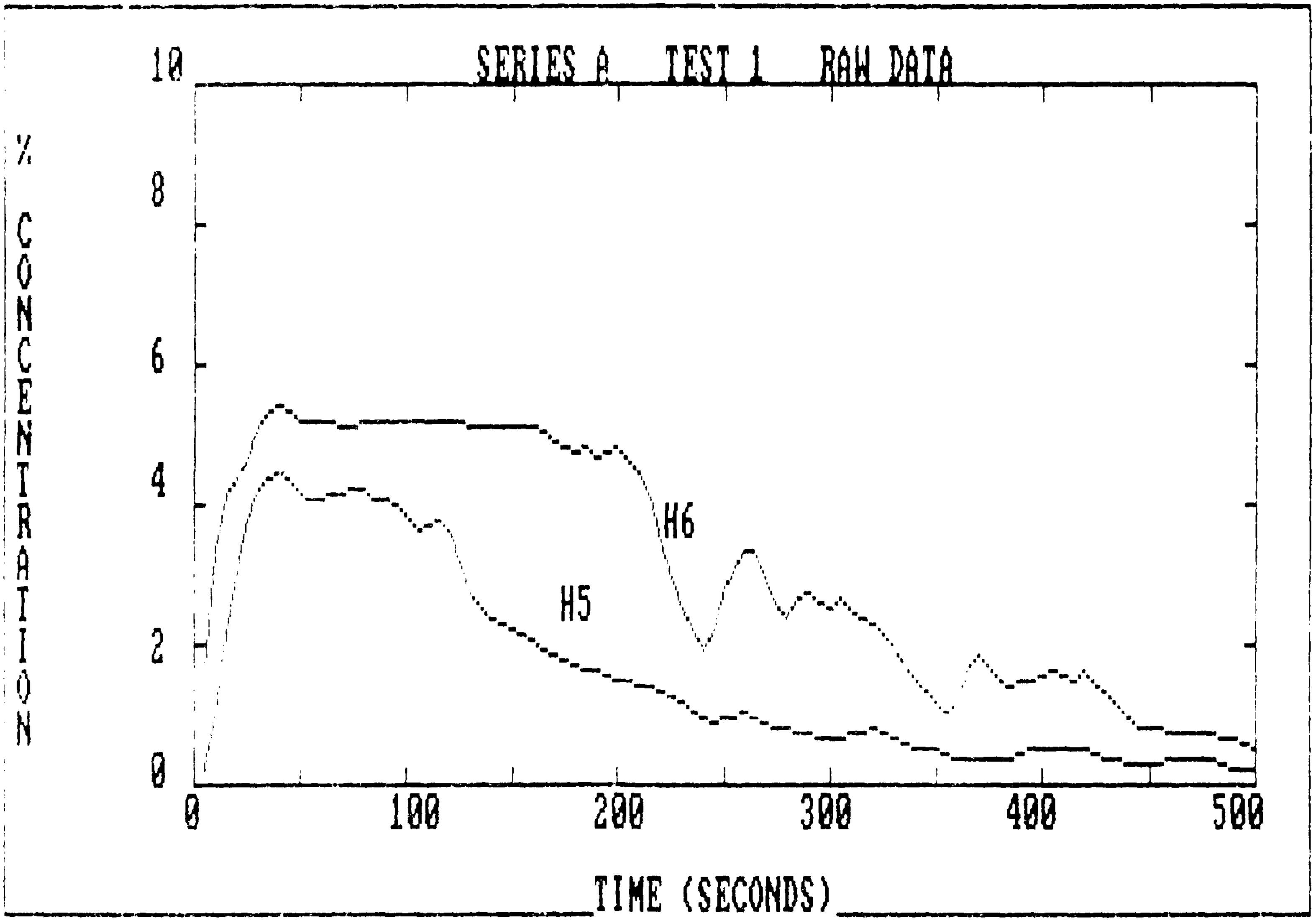



Figure C-3. Raw Halon Concentrations for Series A, Test 1, Probes H5 and H6.

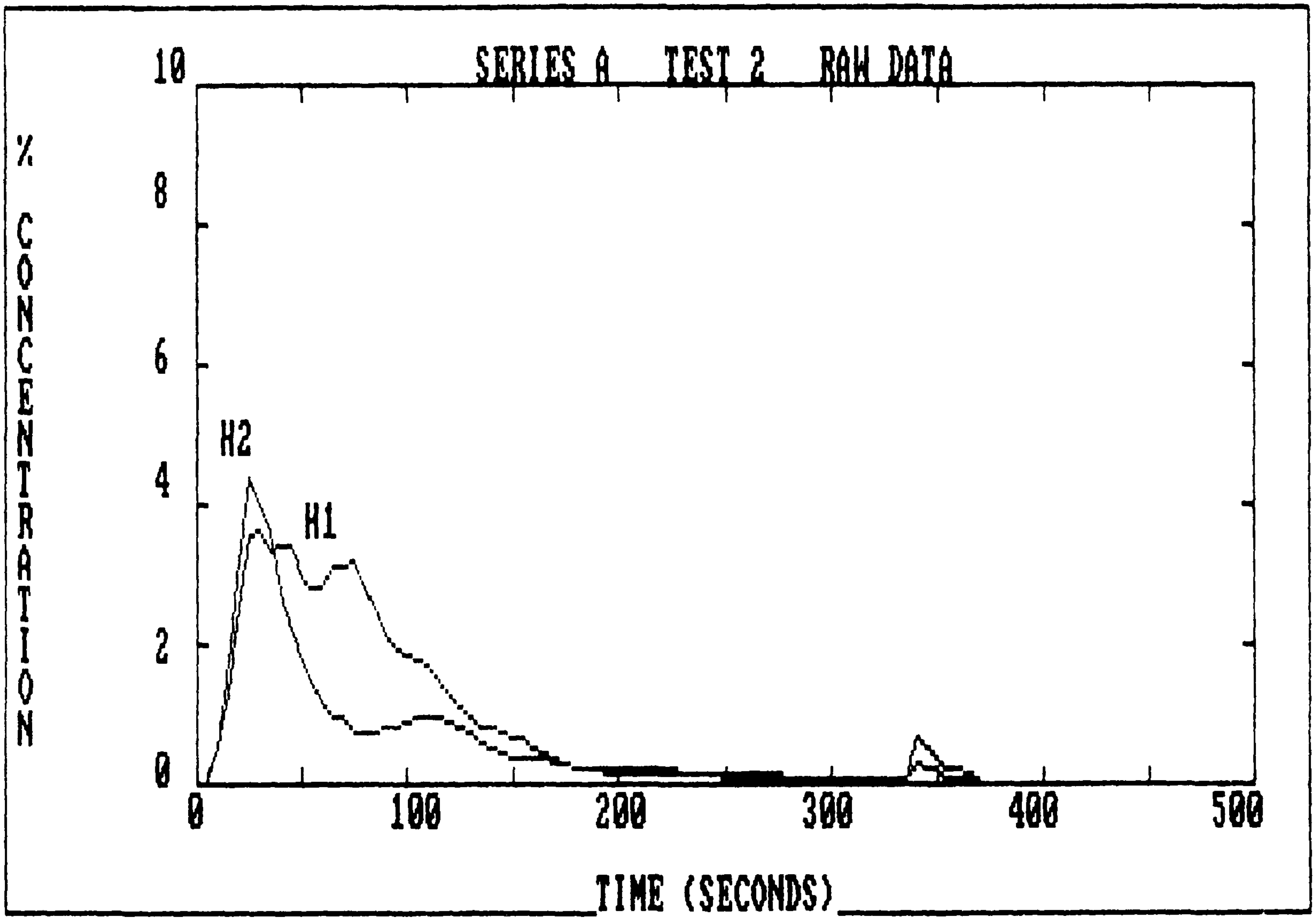



Figure C-4. Raw Halon Concentrations for Series A, Test 2, Probes H1 and H2.

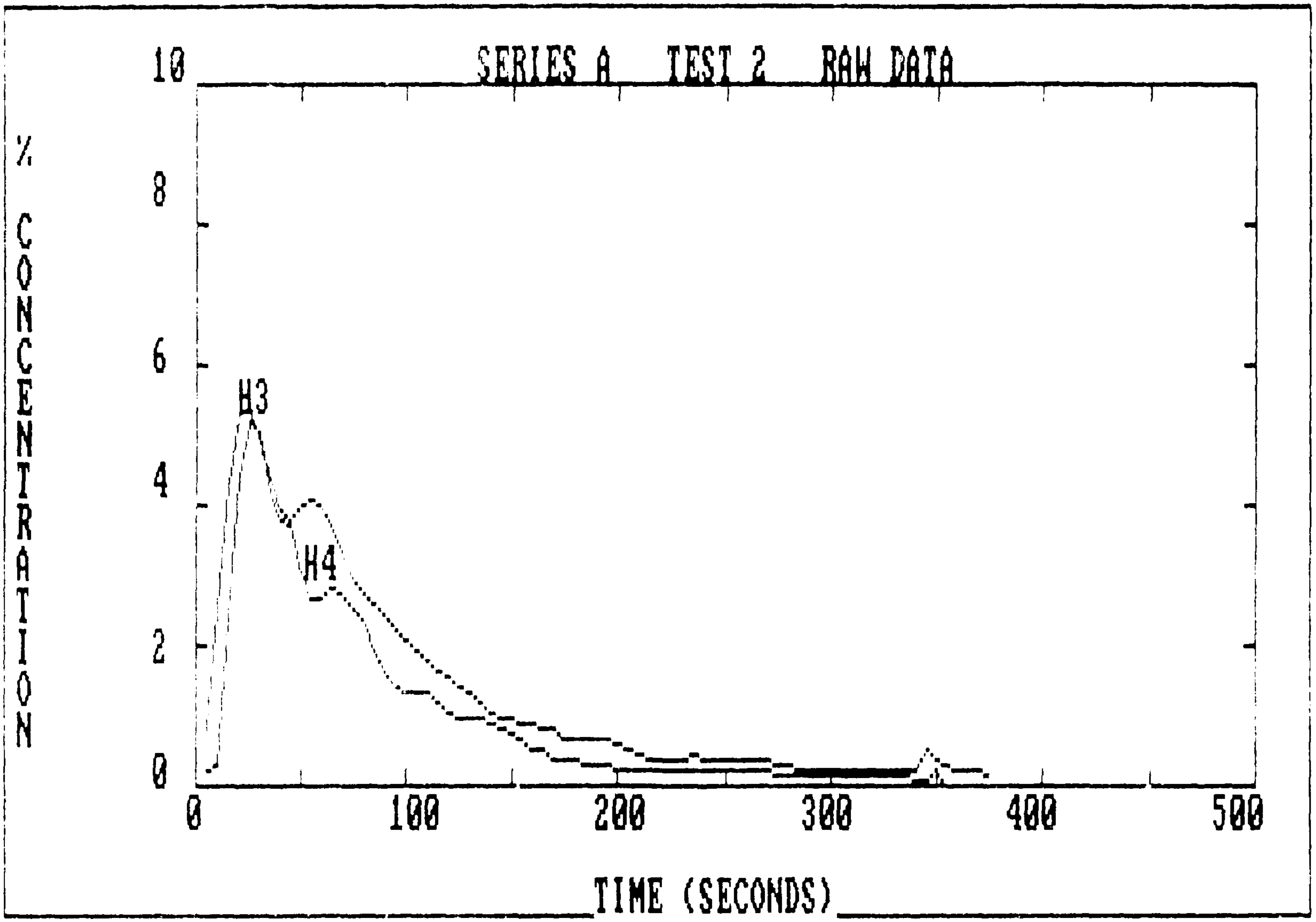



Figure C-5. Raw Halon Concentrations for Series A, Test 2, Probes H3 and H4.

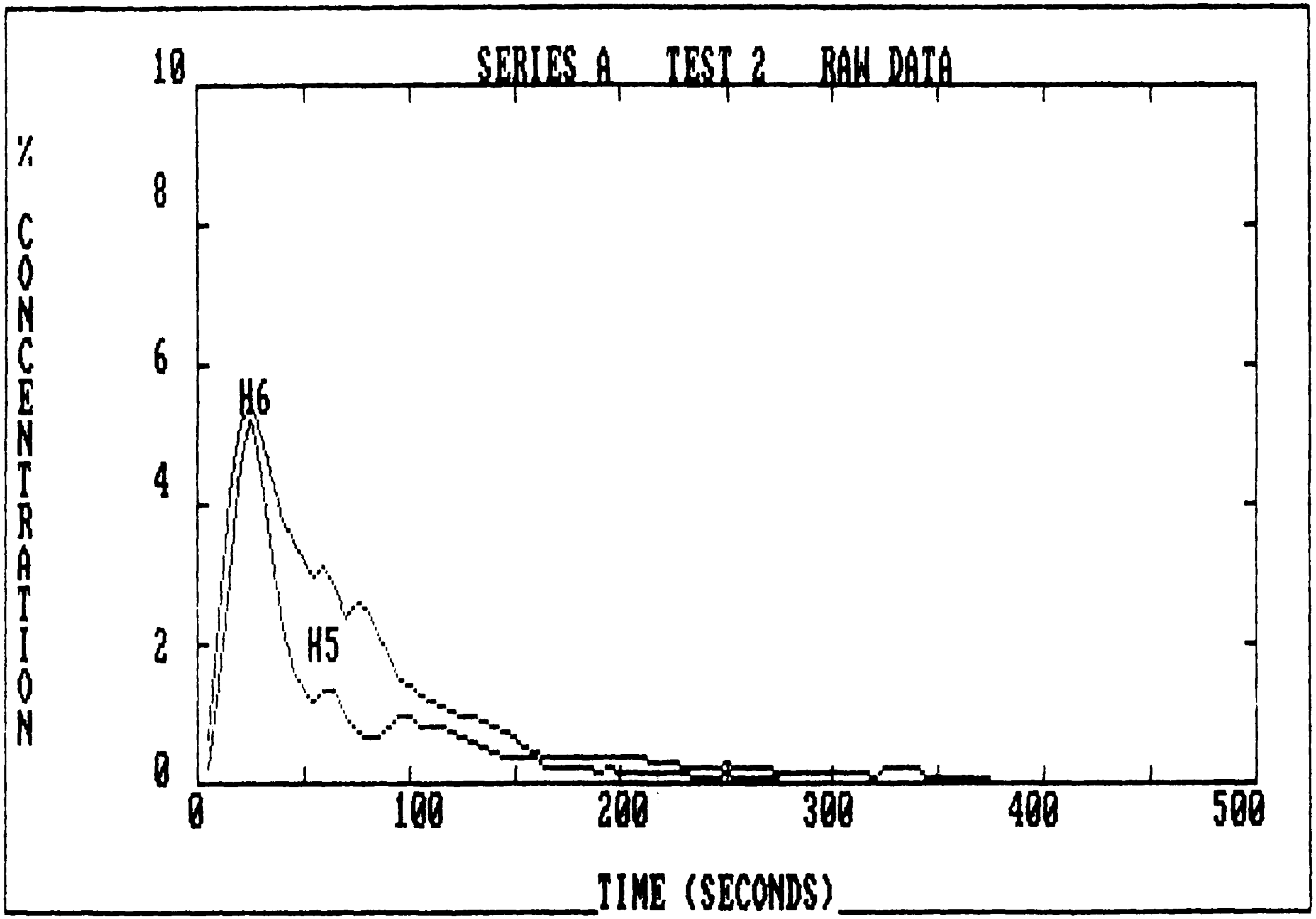



Figure C-6. Raw Halon Concentrations for Series A, Test 2, Probes H5 and H6.

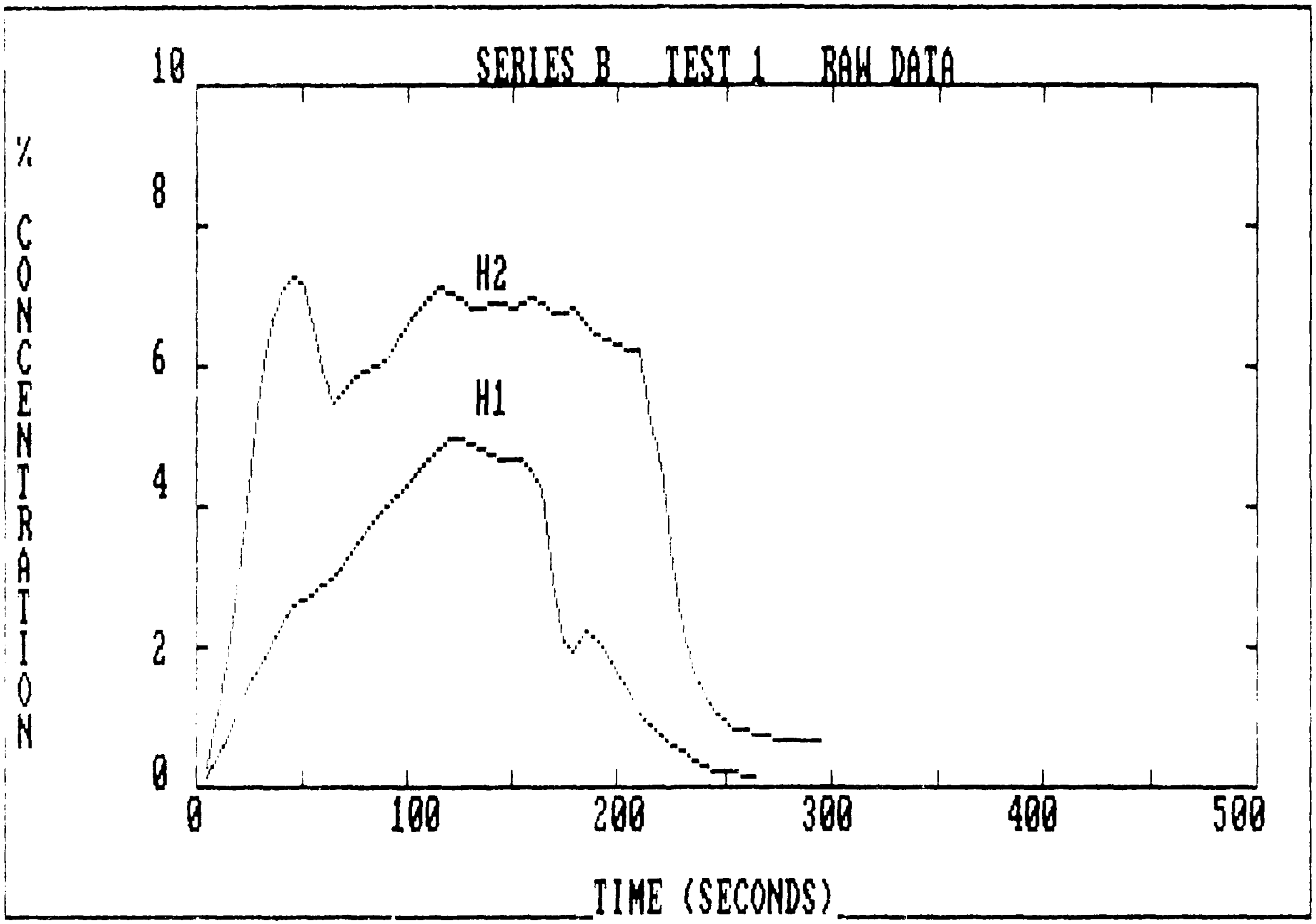



Figure C-7. Raw Halon Concentrations for Series B, Test 1, Probes H1 and H2.

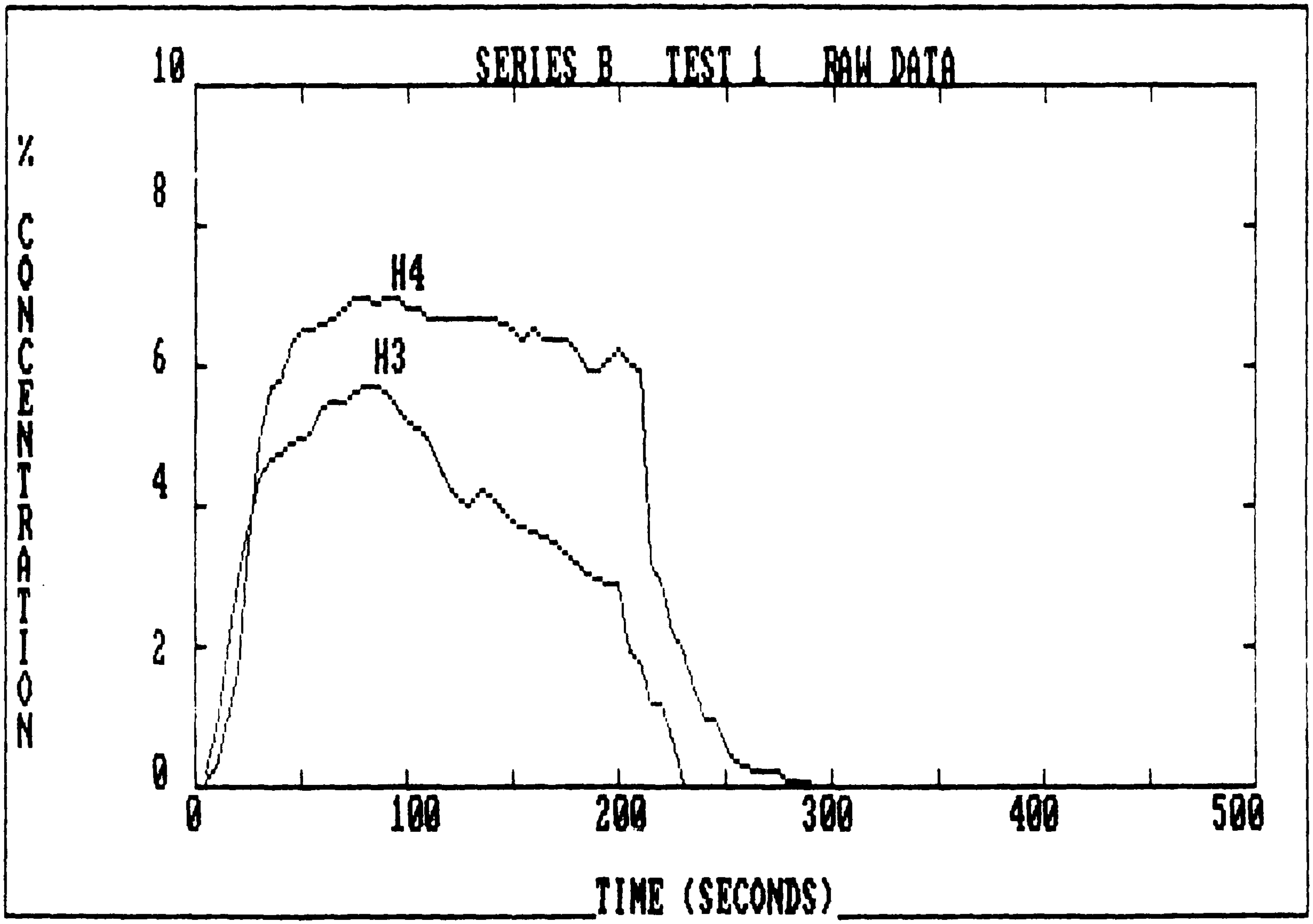



Figure C-8. Raw Halon Concentrations for Series B, Test 1, Probes H3 and H4.

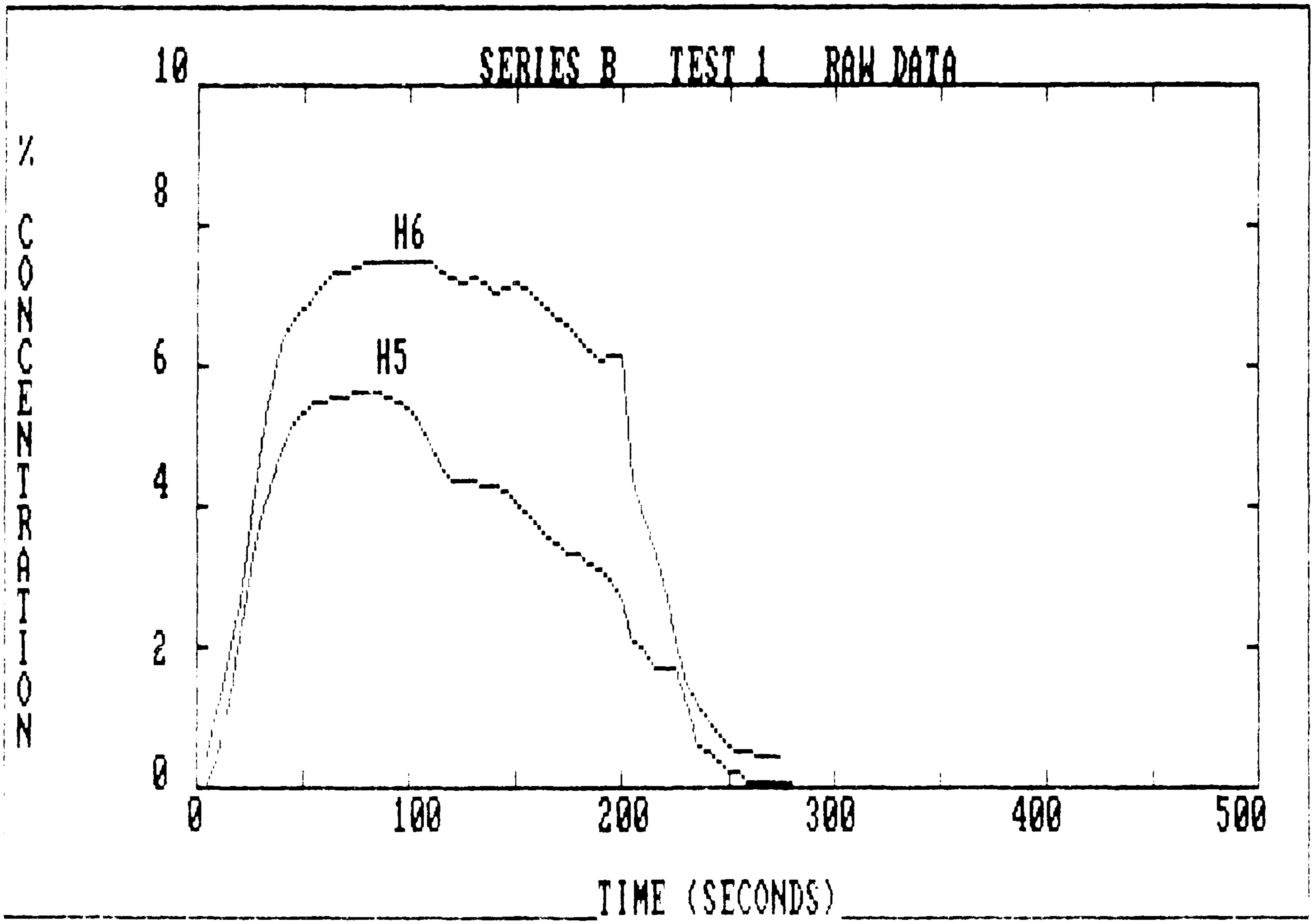



Figure C-9. Raw Halon Concentrations for Series B, Test 1, Probes H5 and H6.

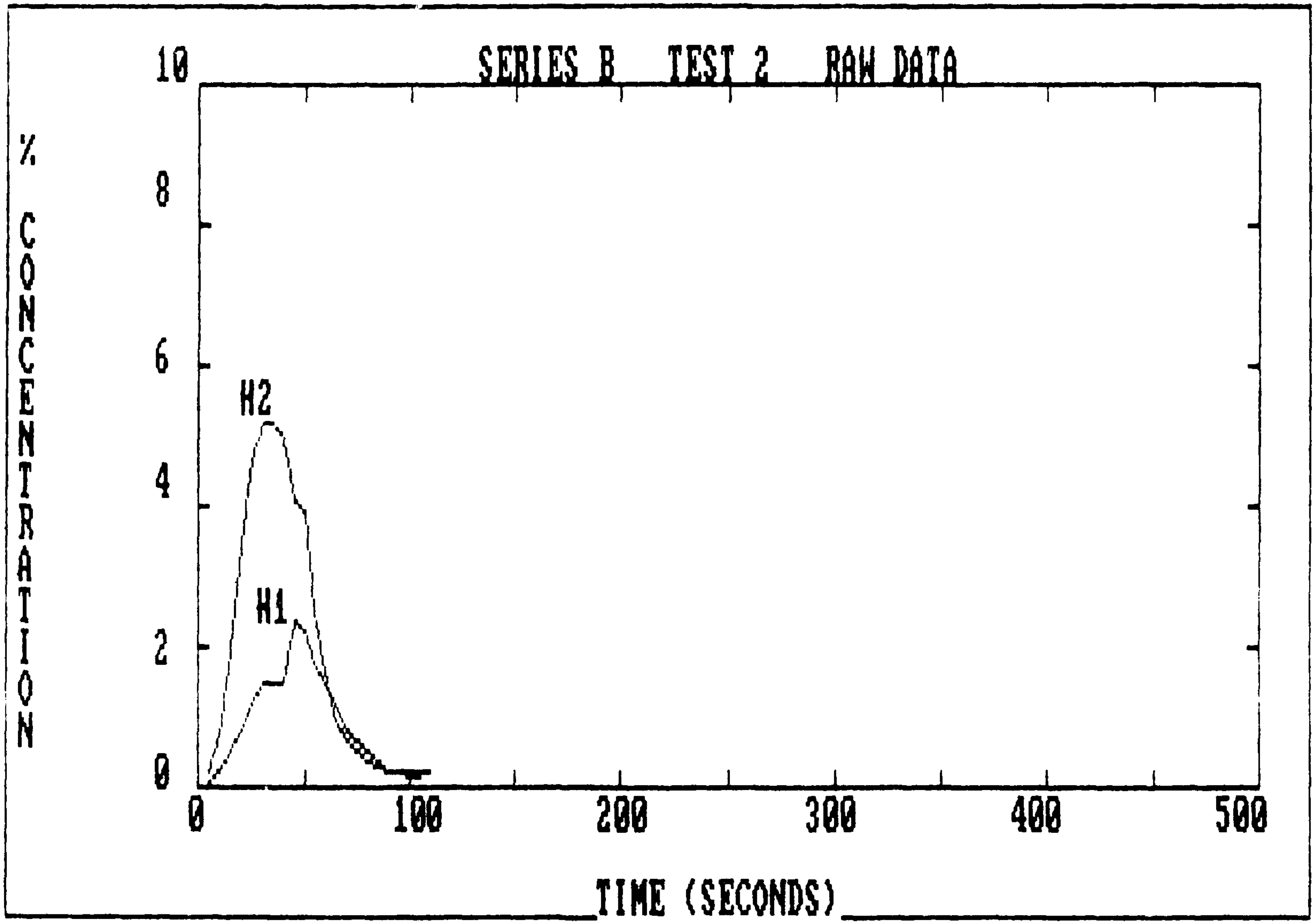



Figure C-10. Raw Halon Concentrations for Series B, Test 2, Probes H1 and H2.

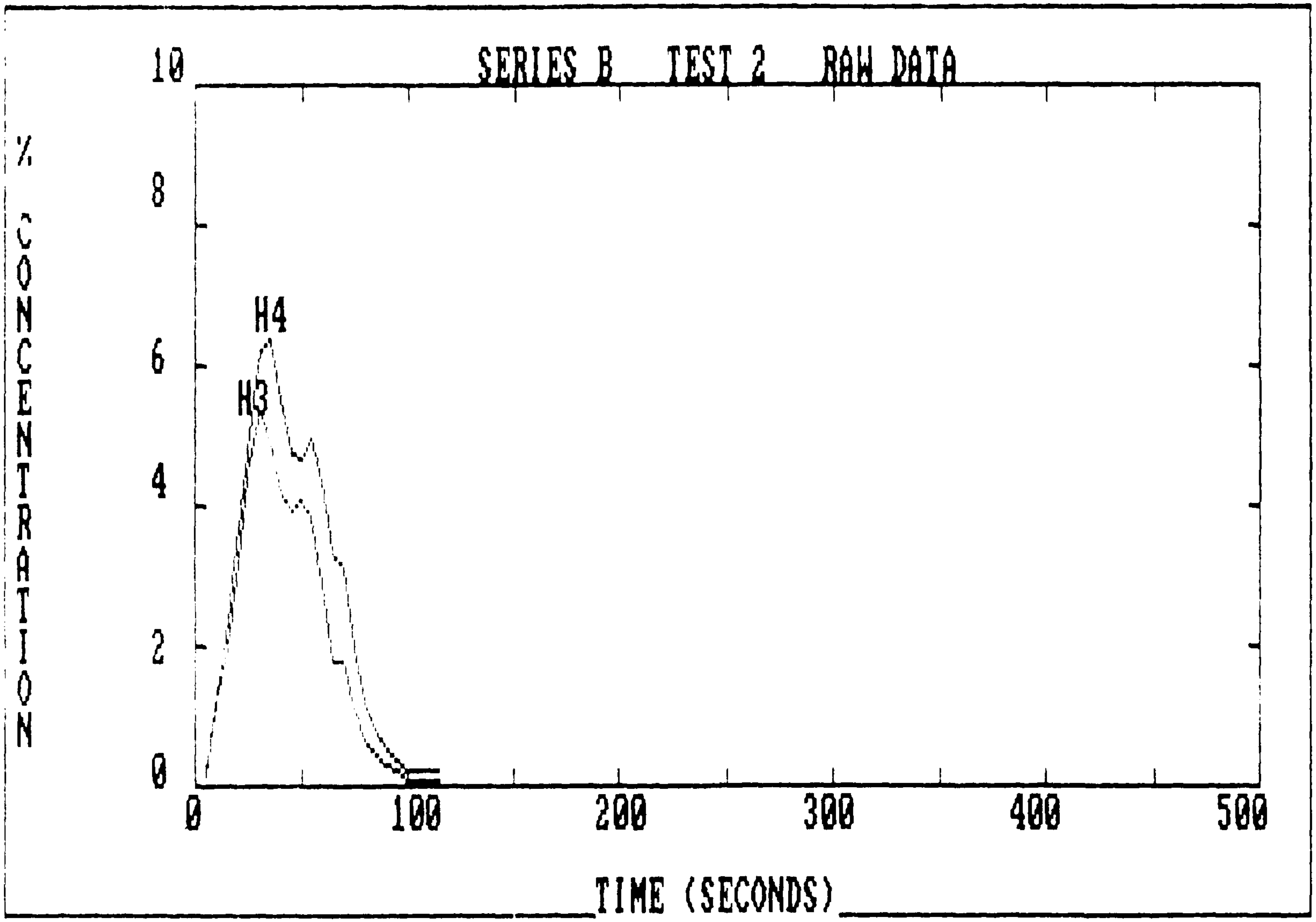



Figure C-11. Raw Halon Concentrations for Series B, Test 2, Probes H3 and H4.

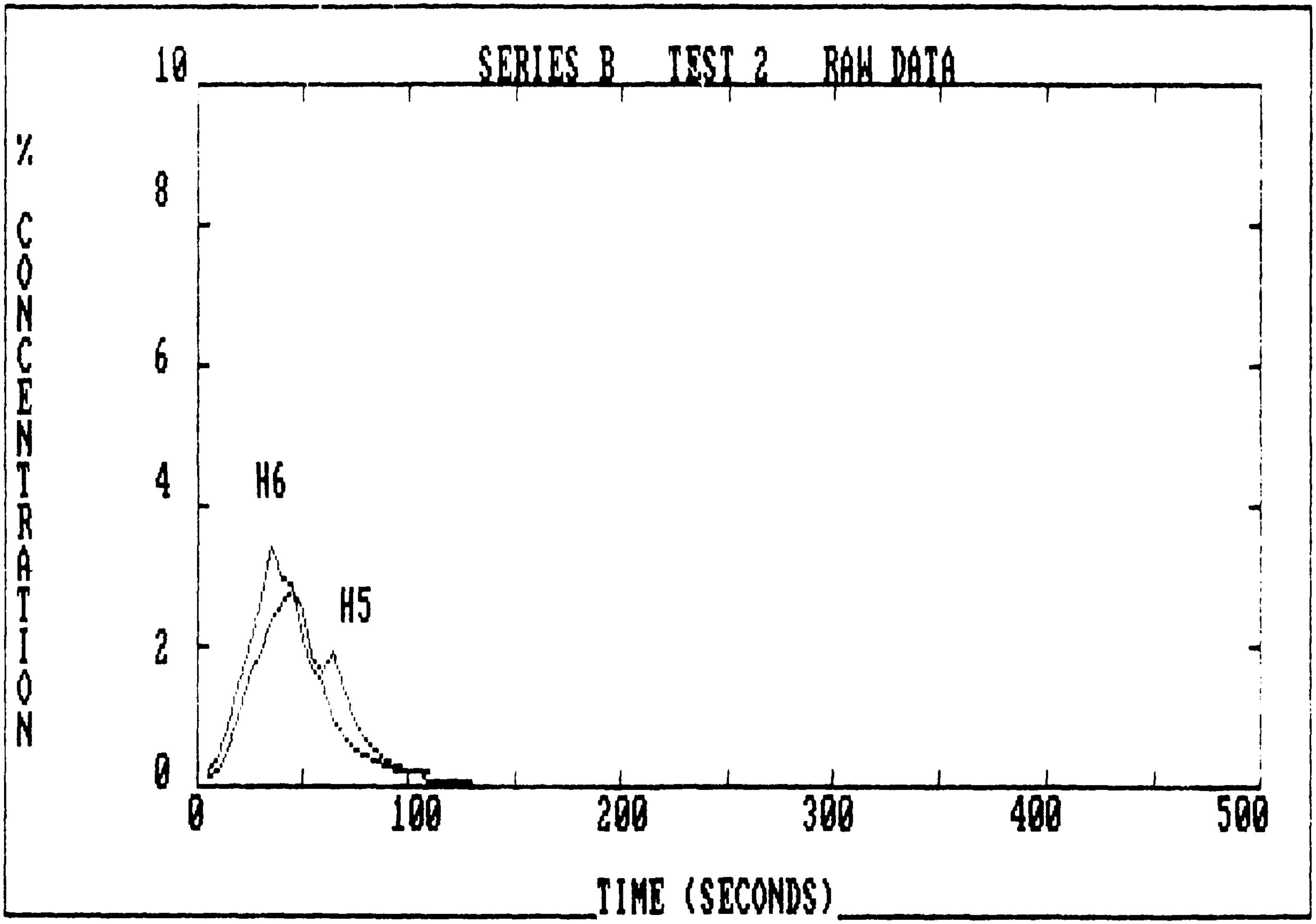



Figure C-12. Raw Halon Concentrations for Series B, Test 2, Probes H5 and H6.

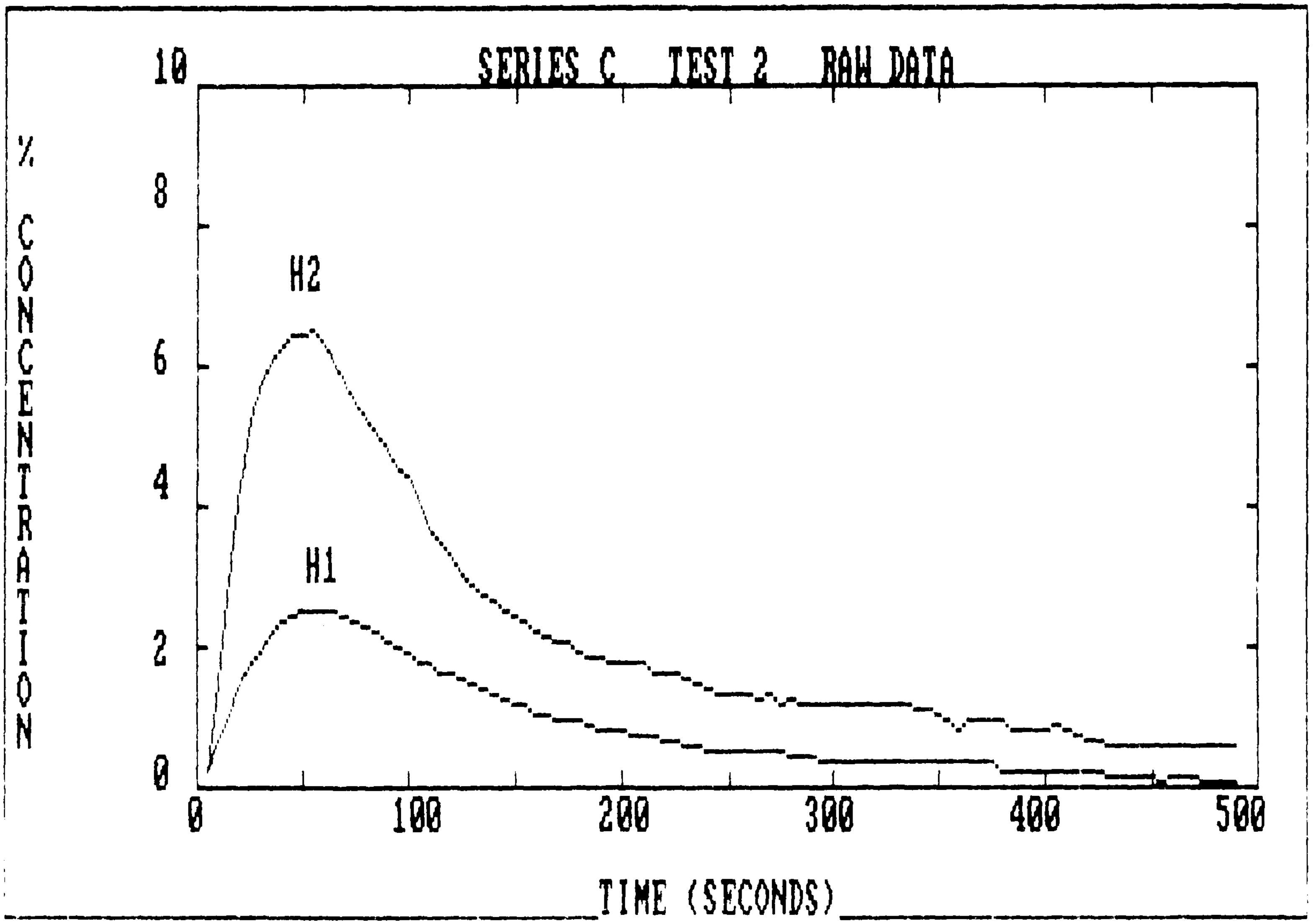



Figure C-13. Raw Halon Concentrations for Series C, Test 2, Probes H1 and H2.

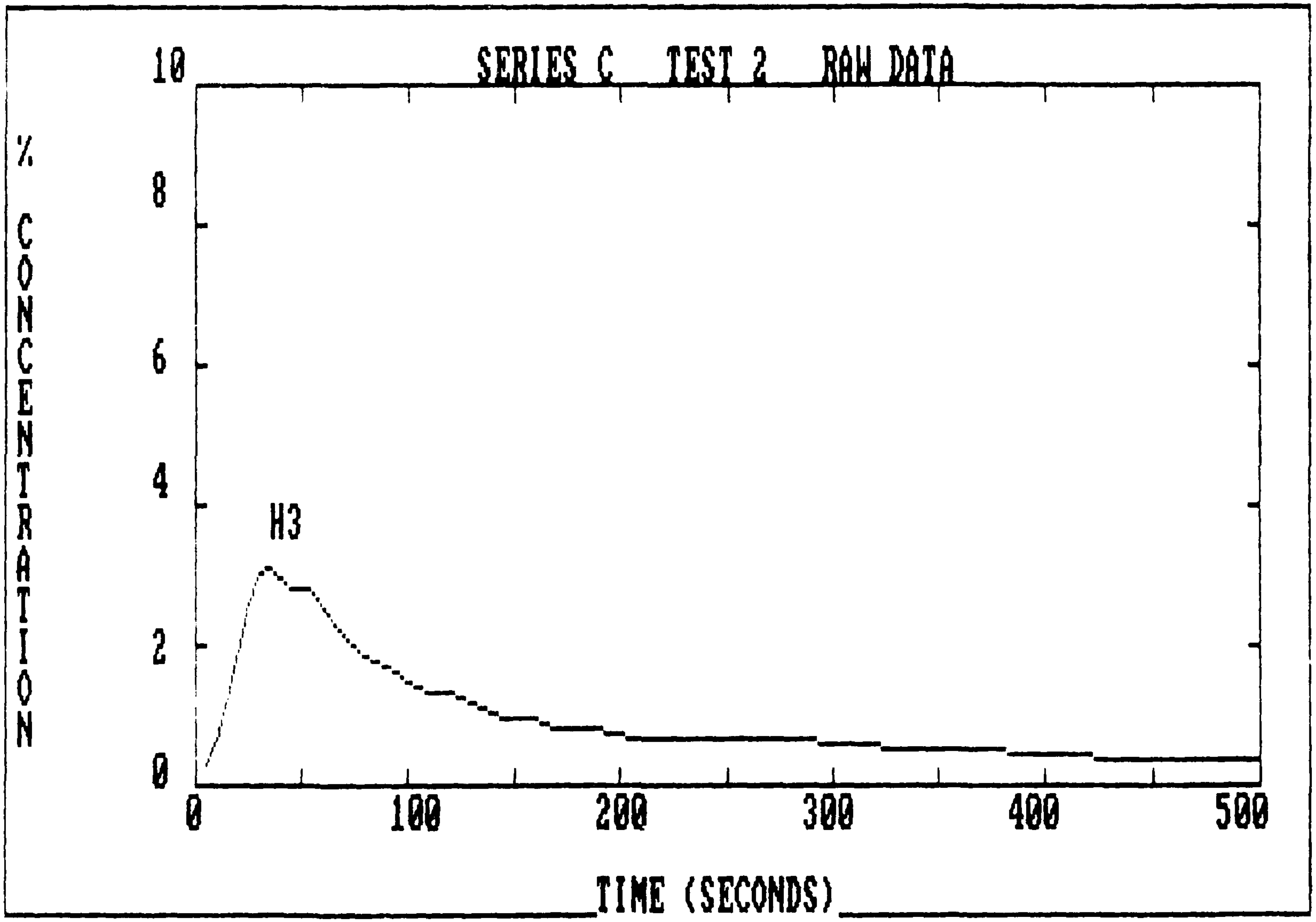



Figure C-14. Raw Halon Concentrations for Series C, Test 2, Probe H3.

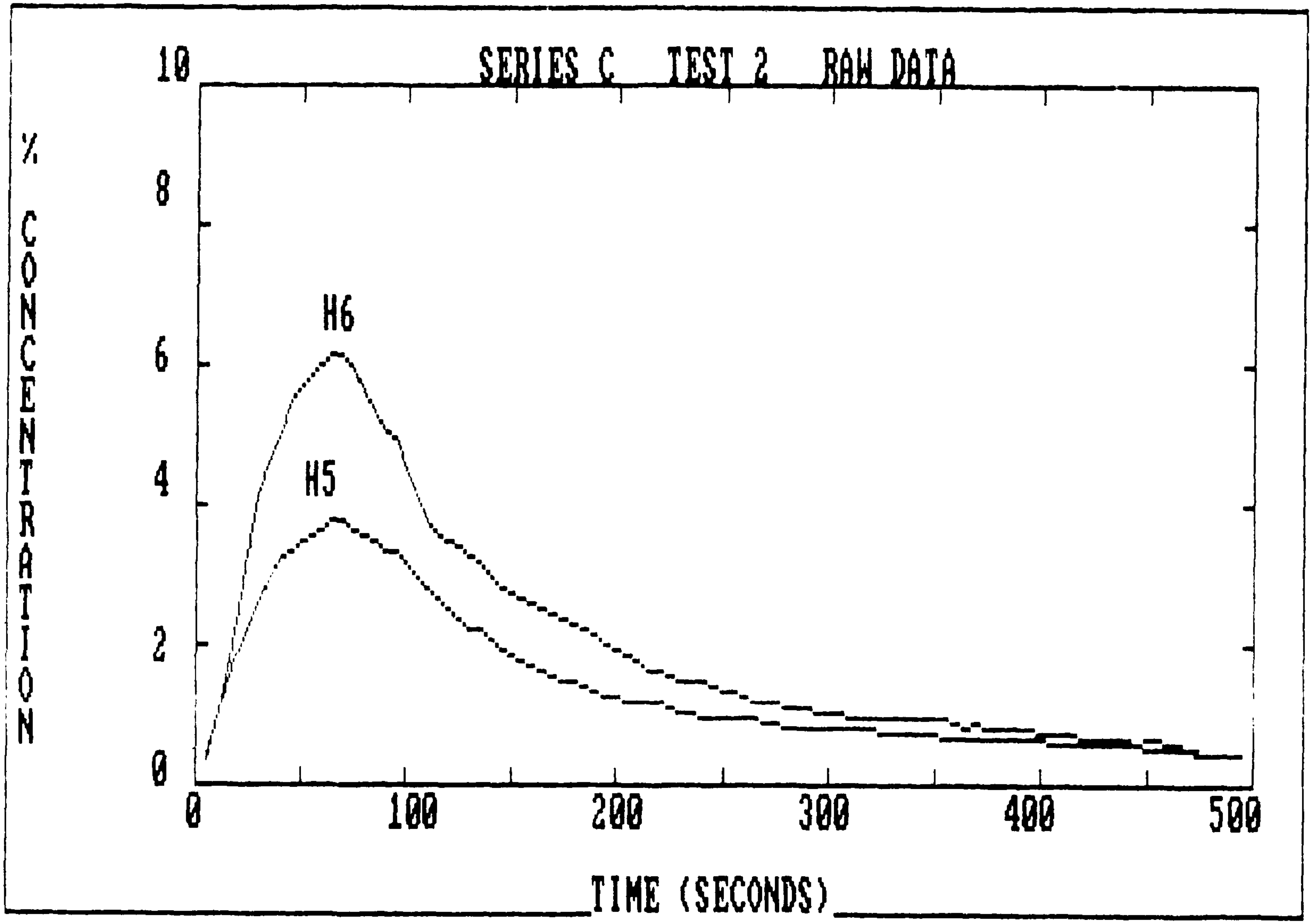



Figure C-15. Raw Halon Concentrations for Series C, Test 2, Probes H5 and H6.

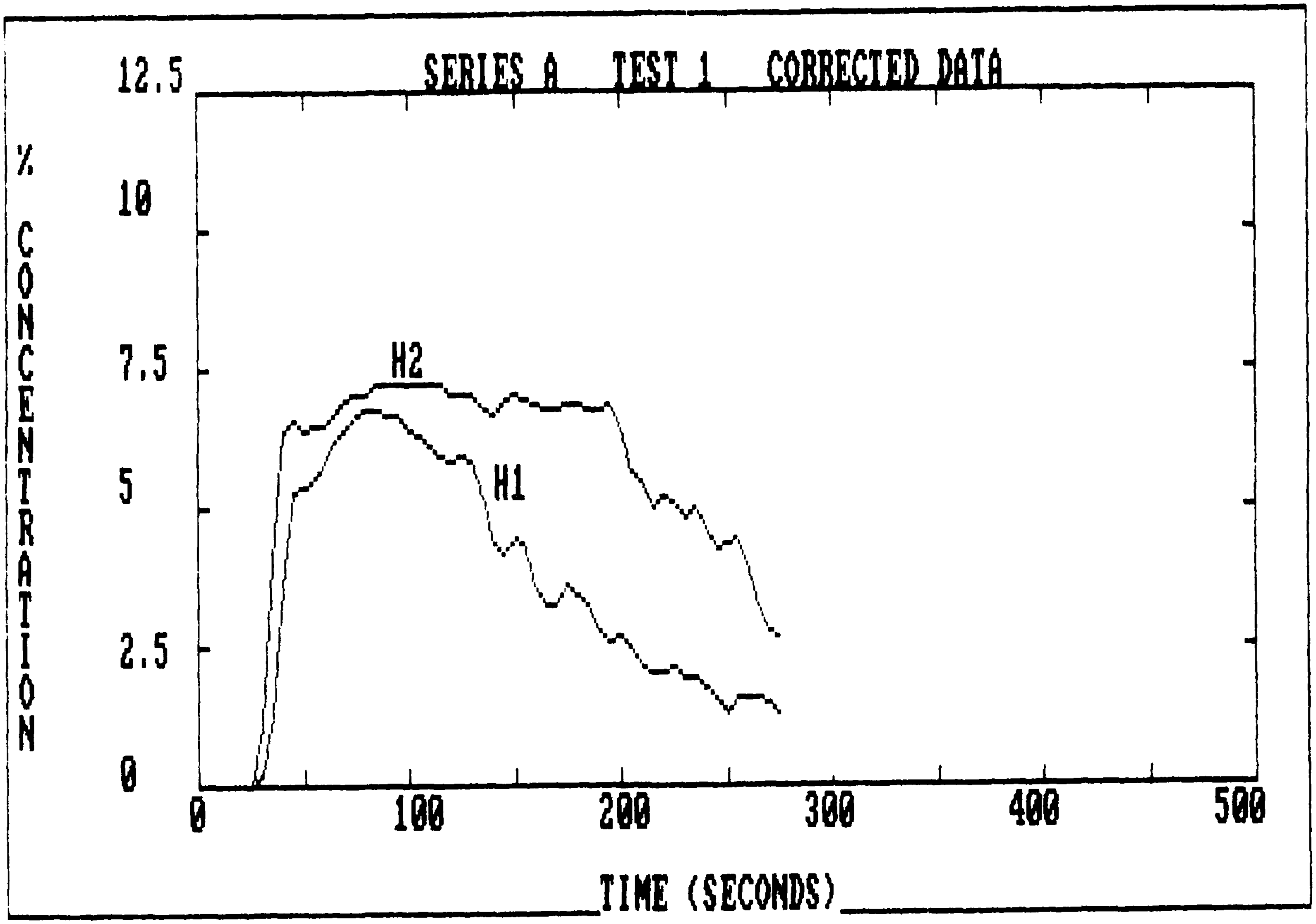



Figure C-16. Corrected Halon Concentrations for Series A, Test 1, Probes H1 and H2.

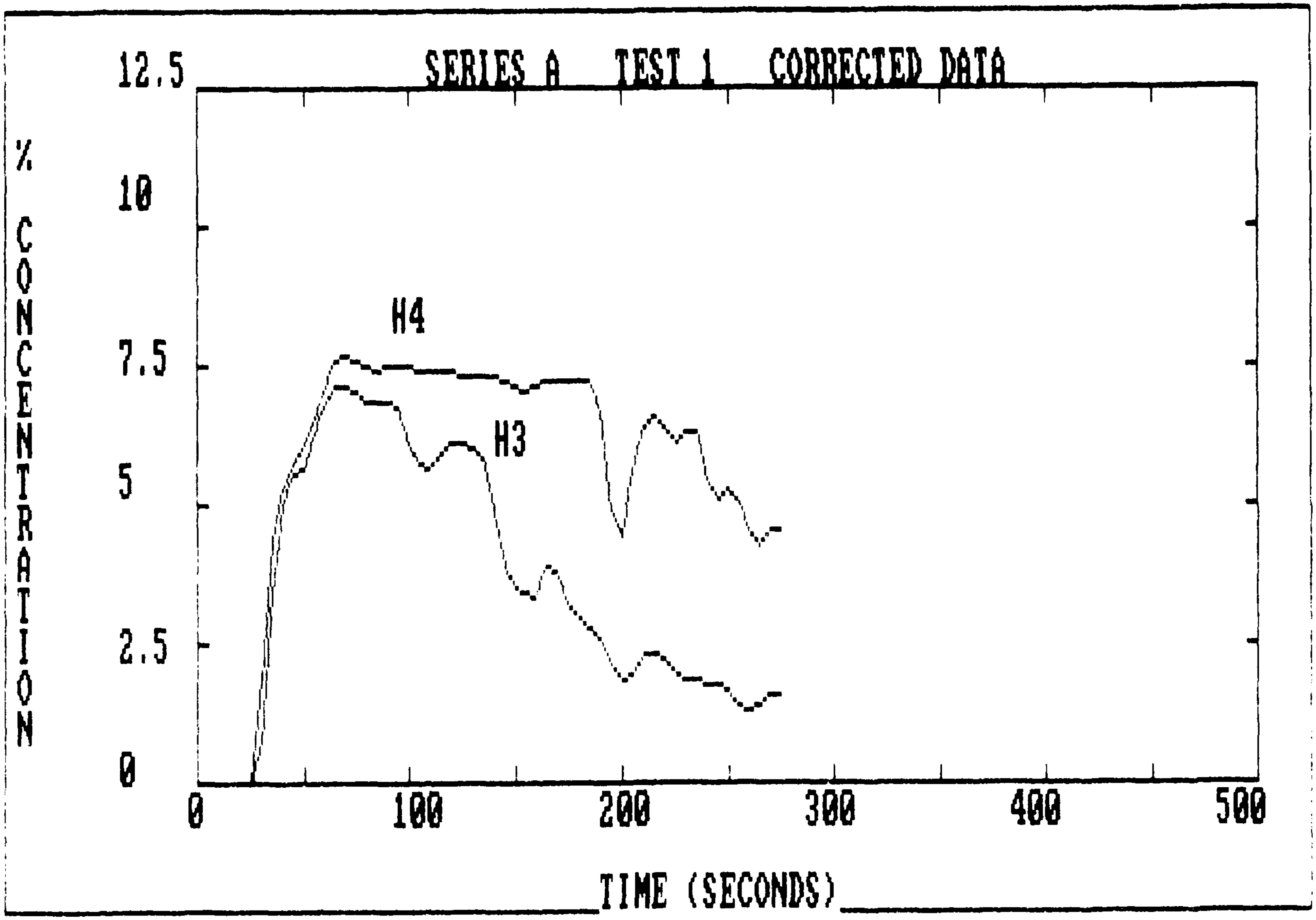



Figure C-17. Corrected Halon Concentrations for Series A, Test 1, Probes H3 and H4.

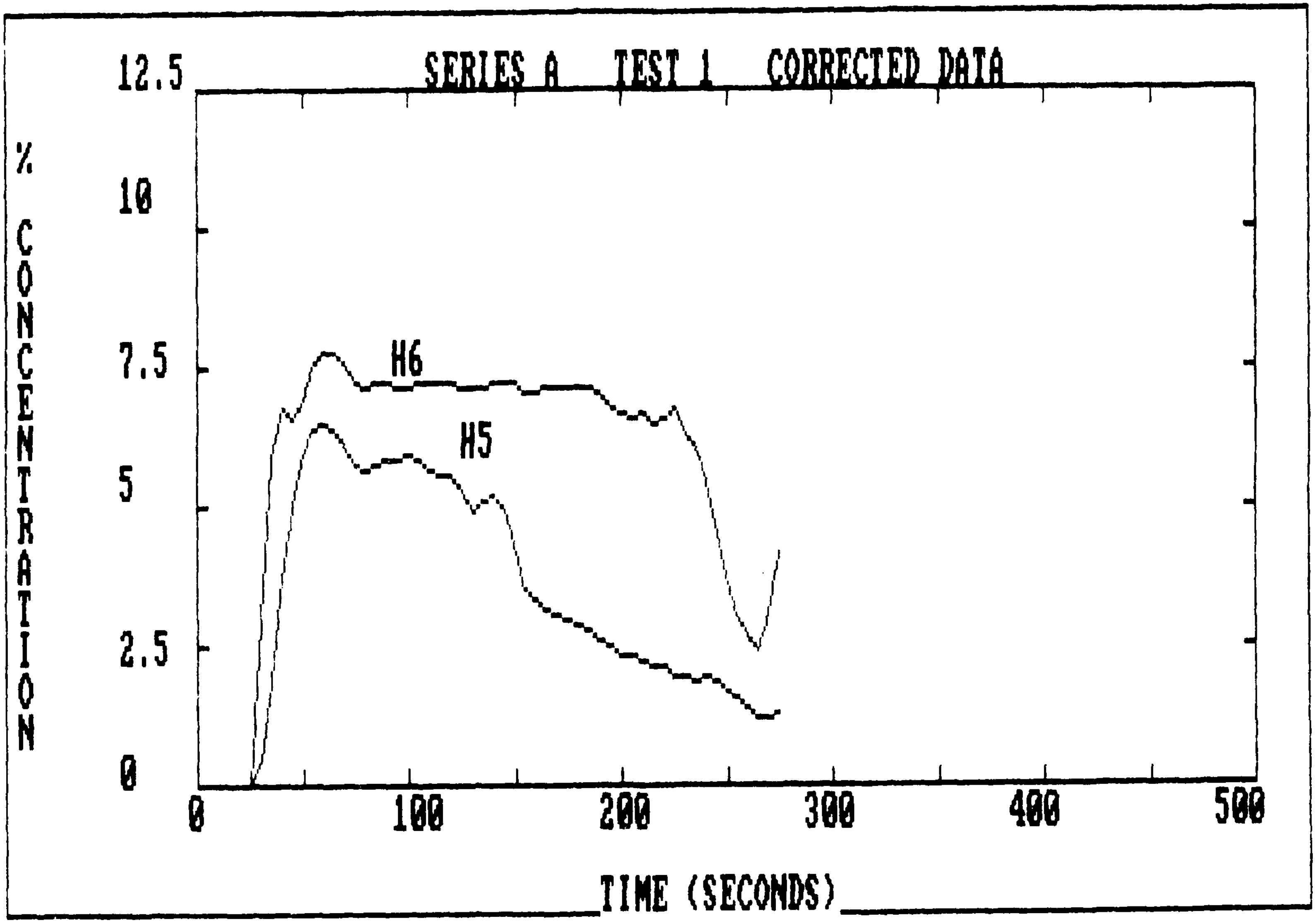



Figure C-18. Corrected Halon Concentrations for Series A, Test 1, Probes H5 and H6.

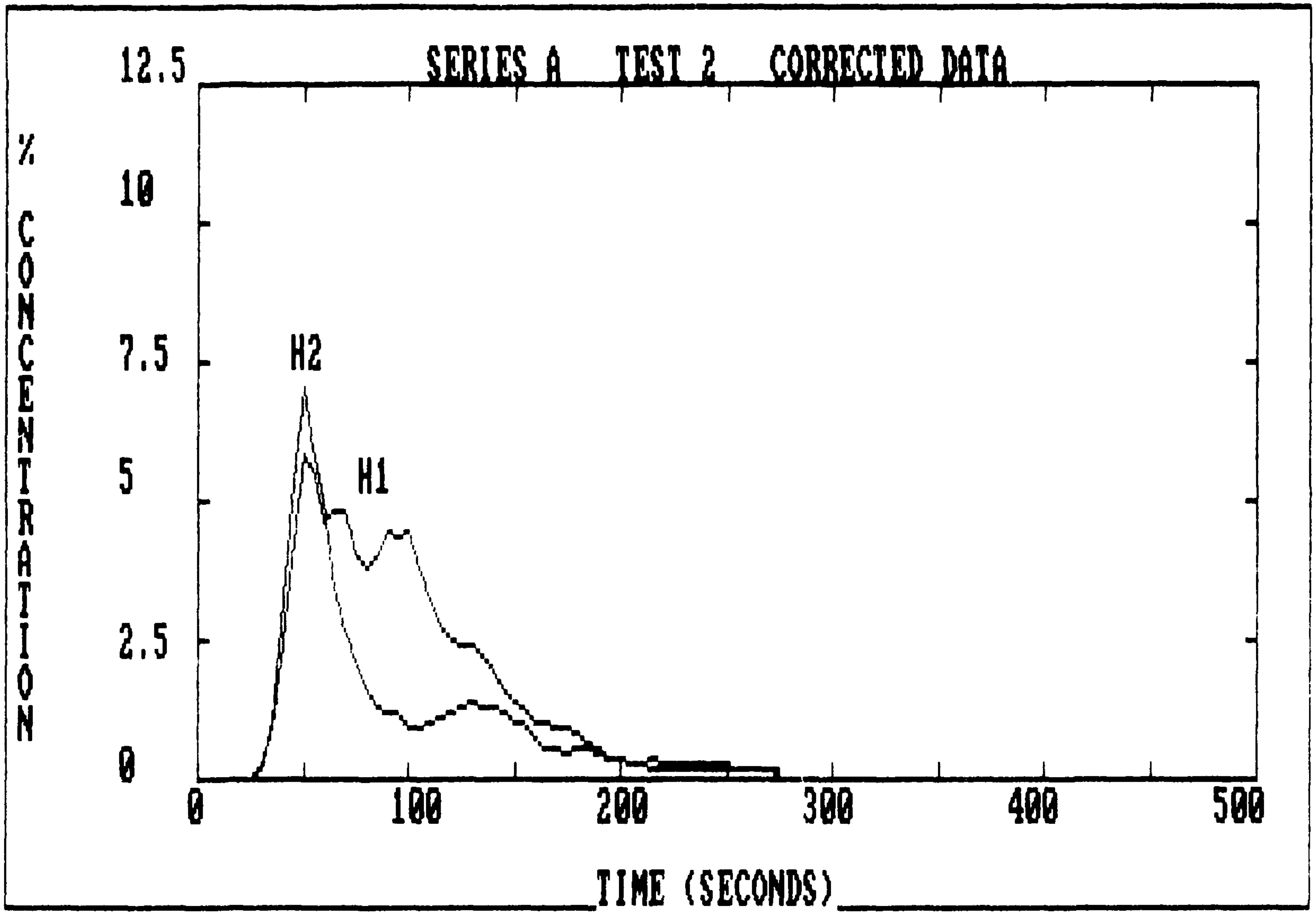



Figure C-19. Corrected Halon Concentrations for Series A, Test 2, Probes H1 and H2.

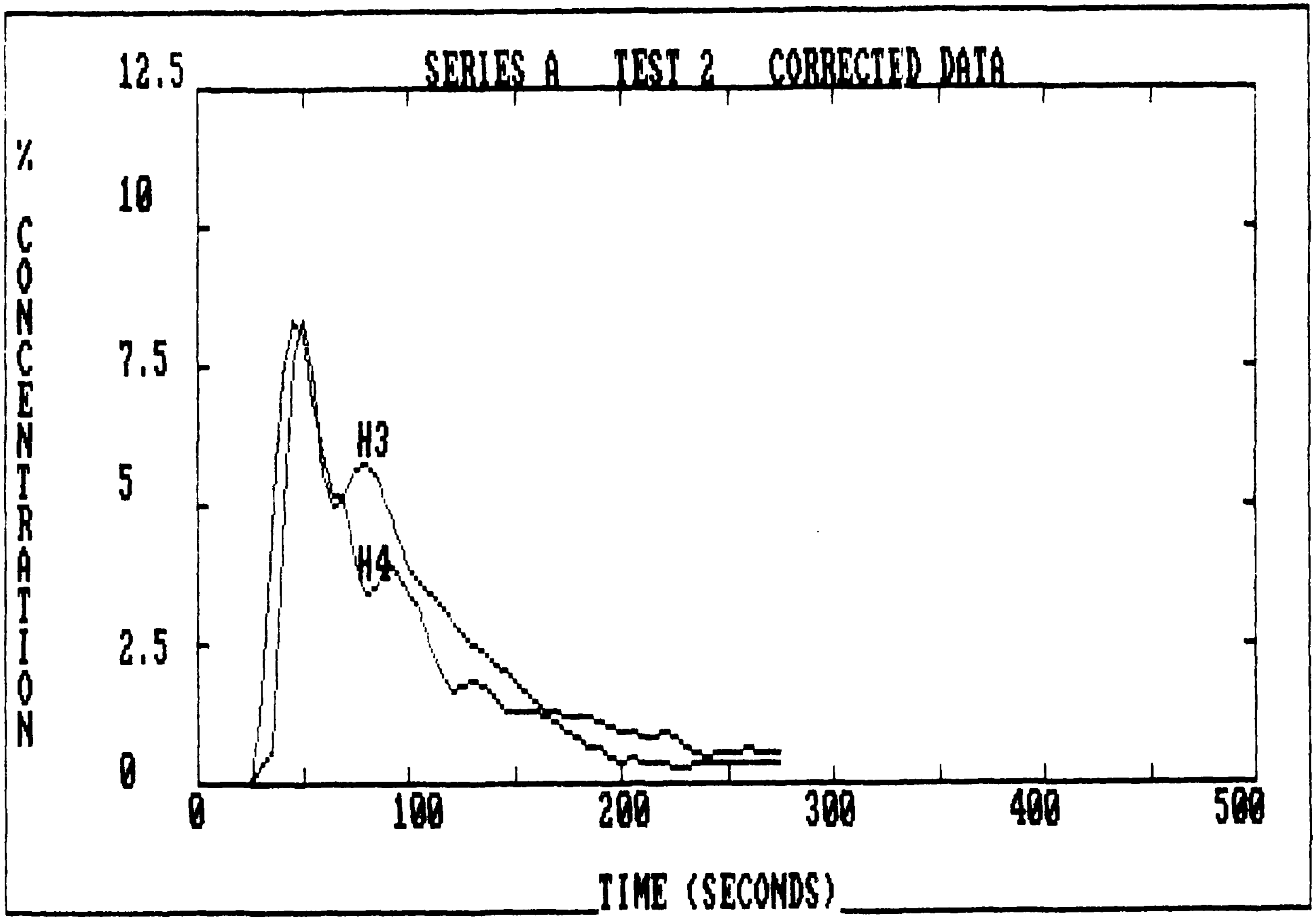



Figure C-20. Corrected Halon Concentrations for Series A, Test 2, Probes H3 and H4.

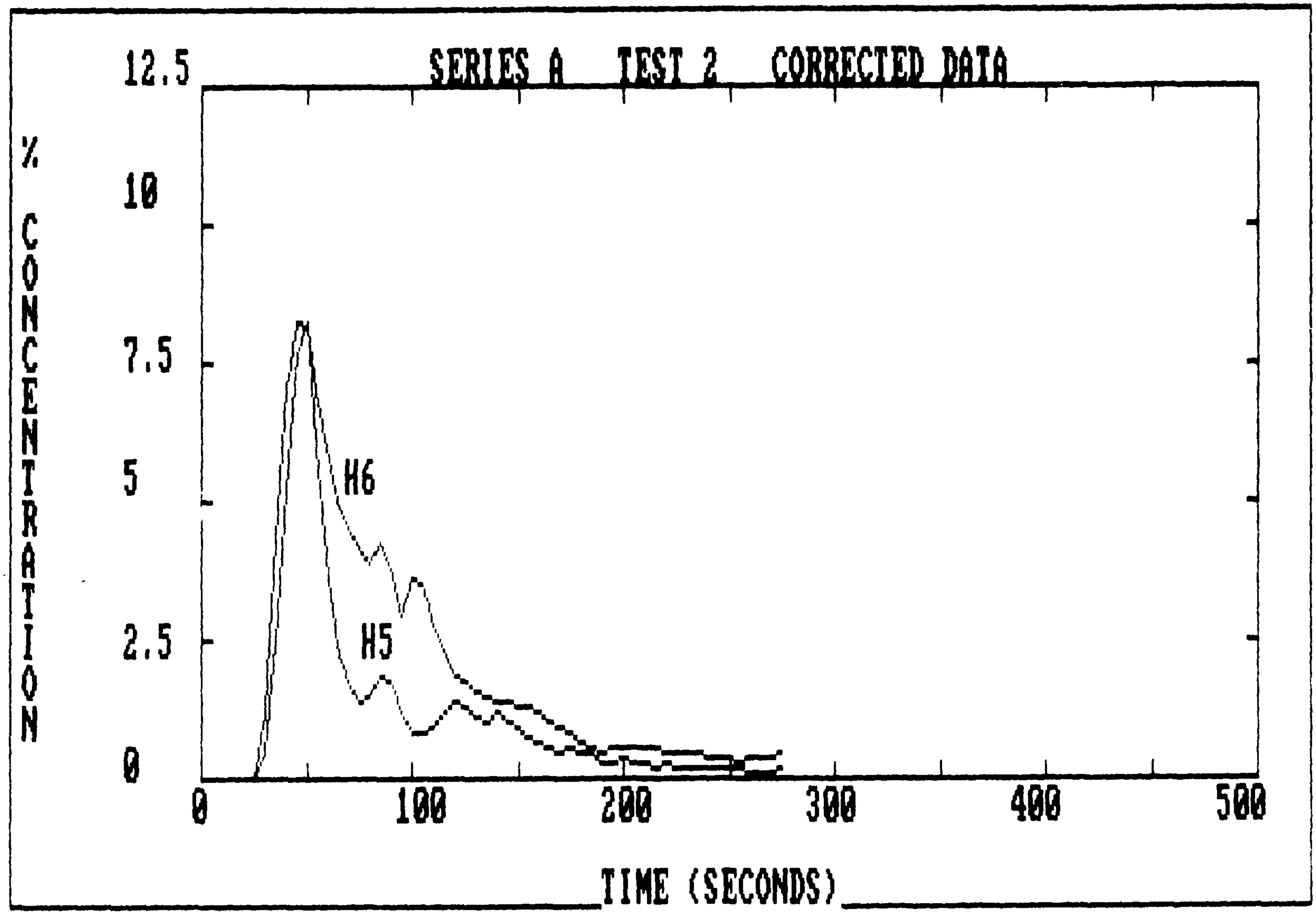



Figure C-21. Corrected Halon Concentrations for Series A, Test 2, Probes H5 and H6.

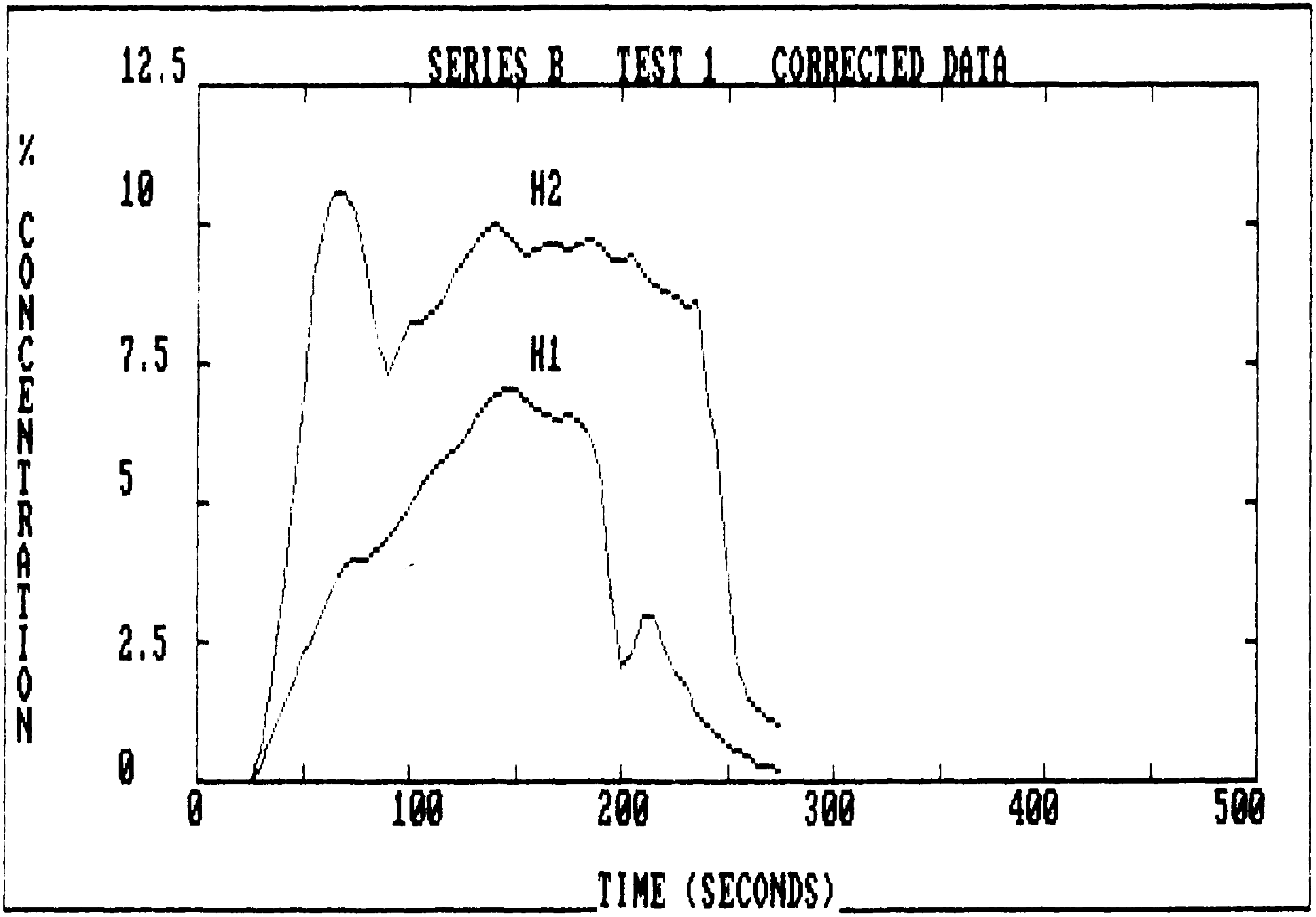



Figure C-22. Corrected Halon Concentrations for Series B, Test 1, Probes H1 and H2.

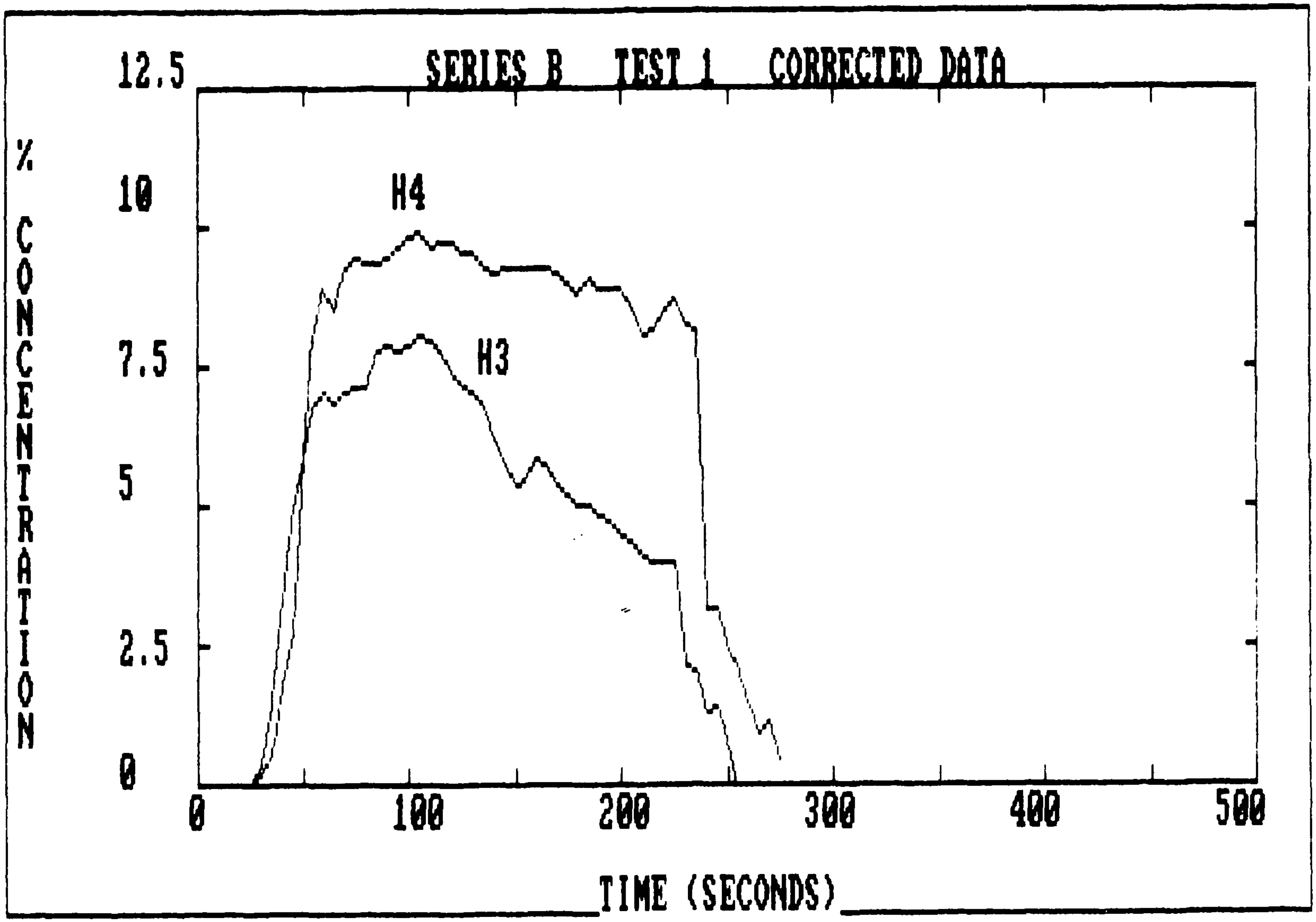



Figure C-23. Corrected Halon Concentrations for Series B, Test 1, Probes H3 and H4.

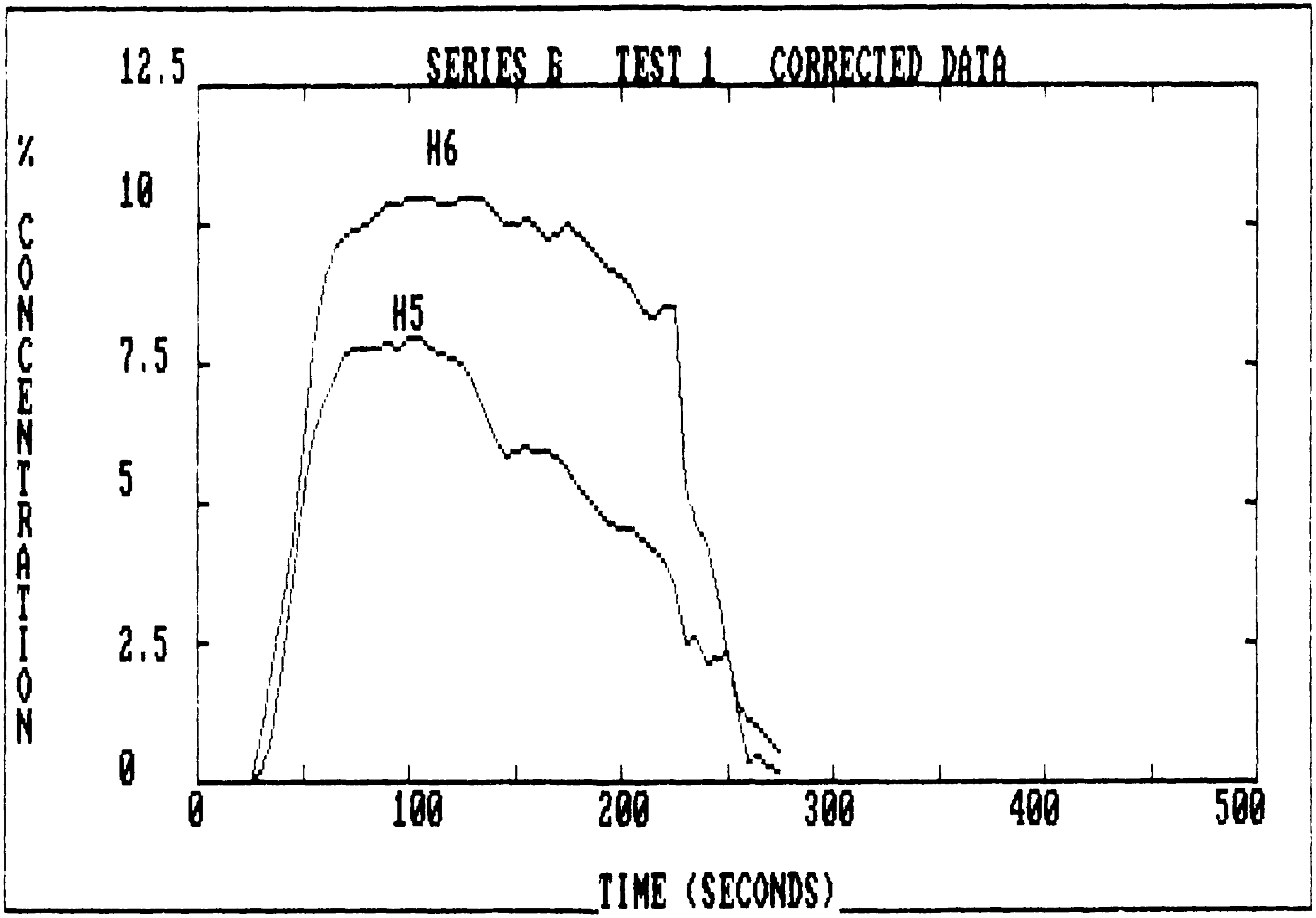



Figure C-24. Corrected Halon Concentrations for Series B, Test 1, Probes H5 and H6.

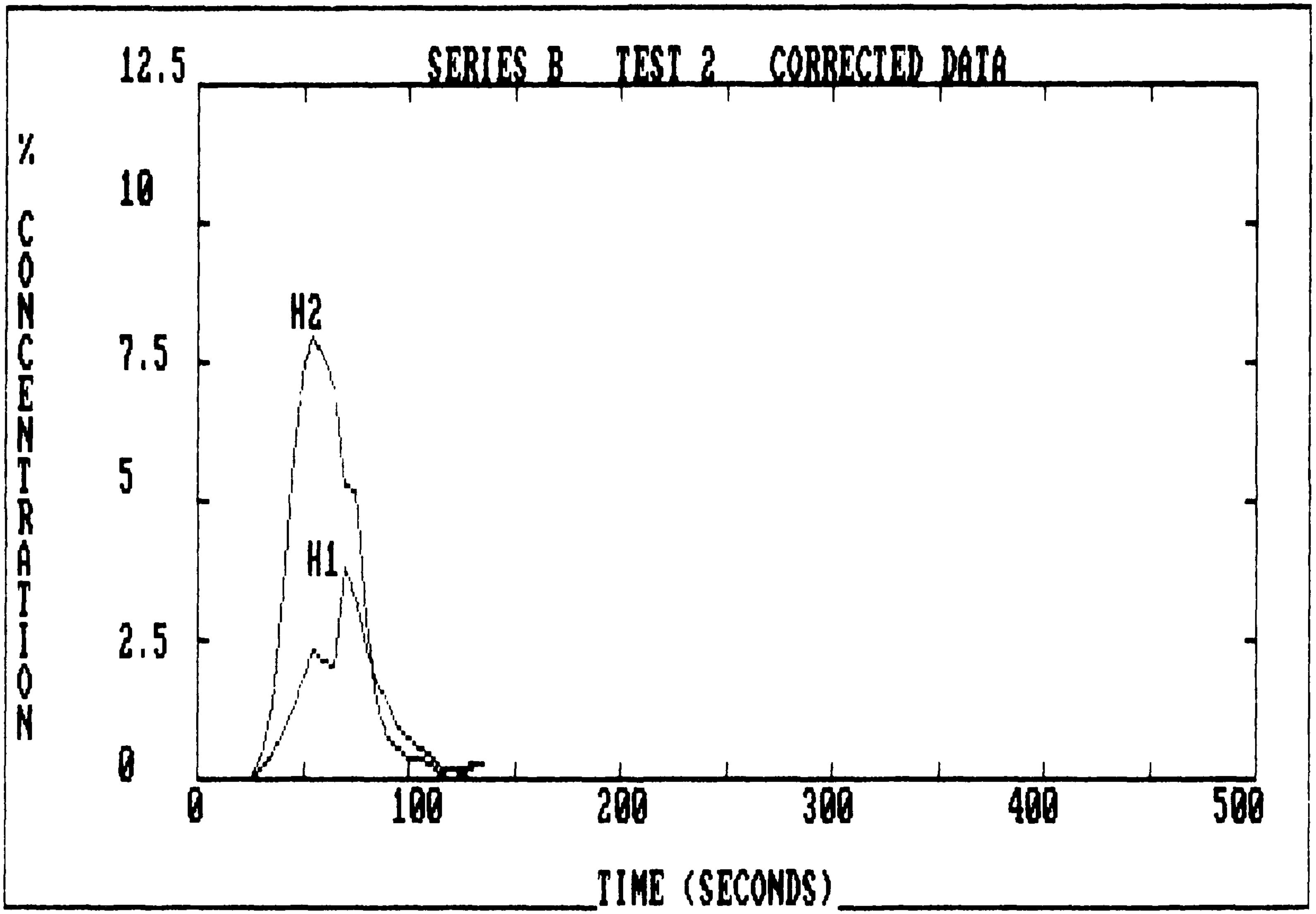



Figure C-25. Corrected Halon Concentrations for Series B, Test 2, Probes H1 and H2.

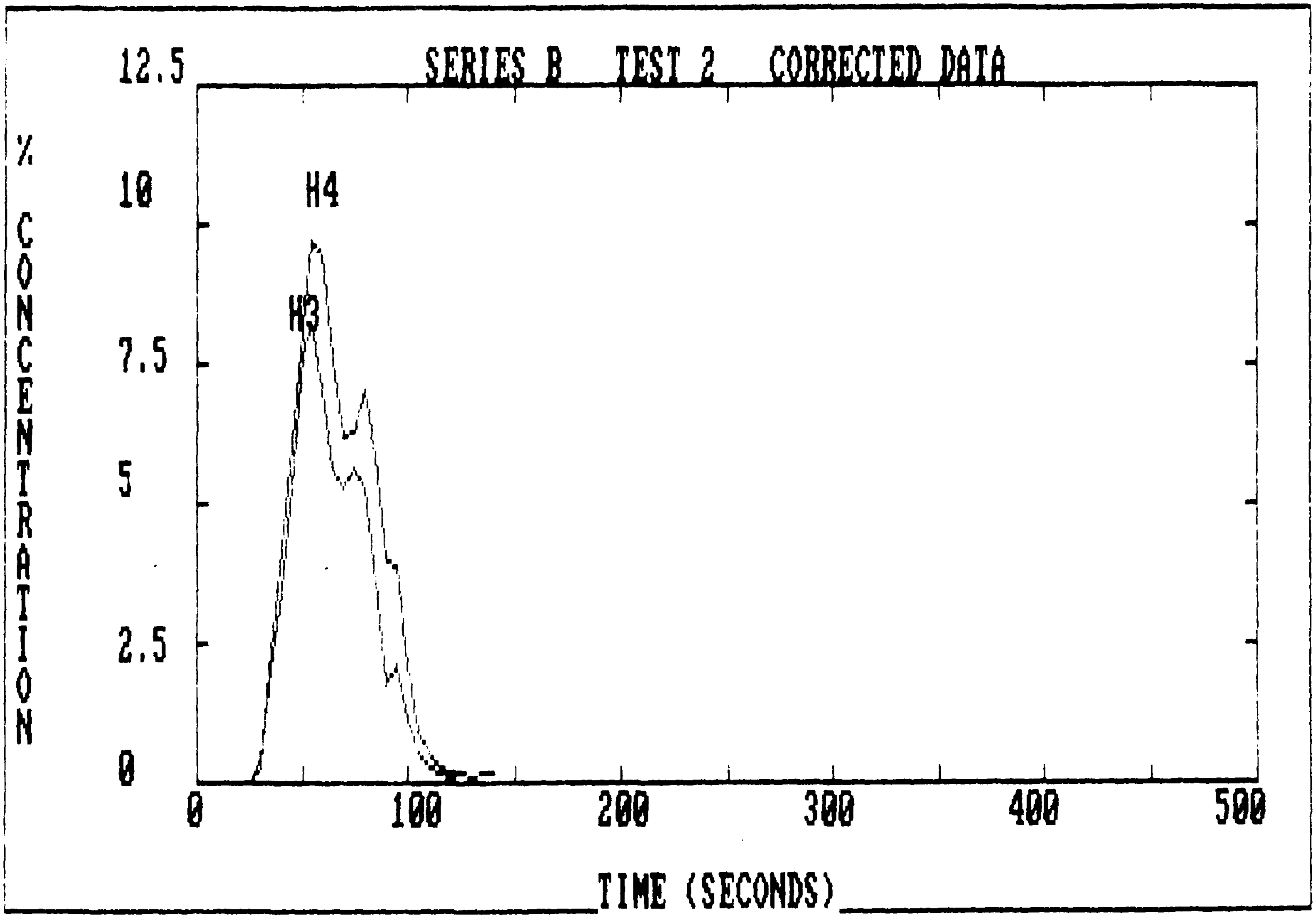



Figure C-26. Corrected Halon Concentrations for Series B, Test 2, Probes H3 and H4.

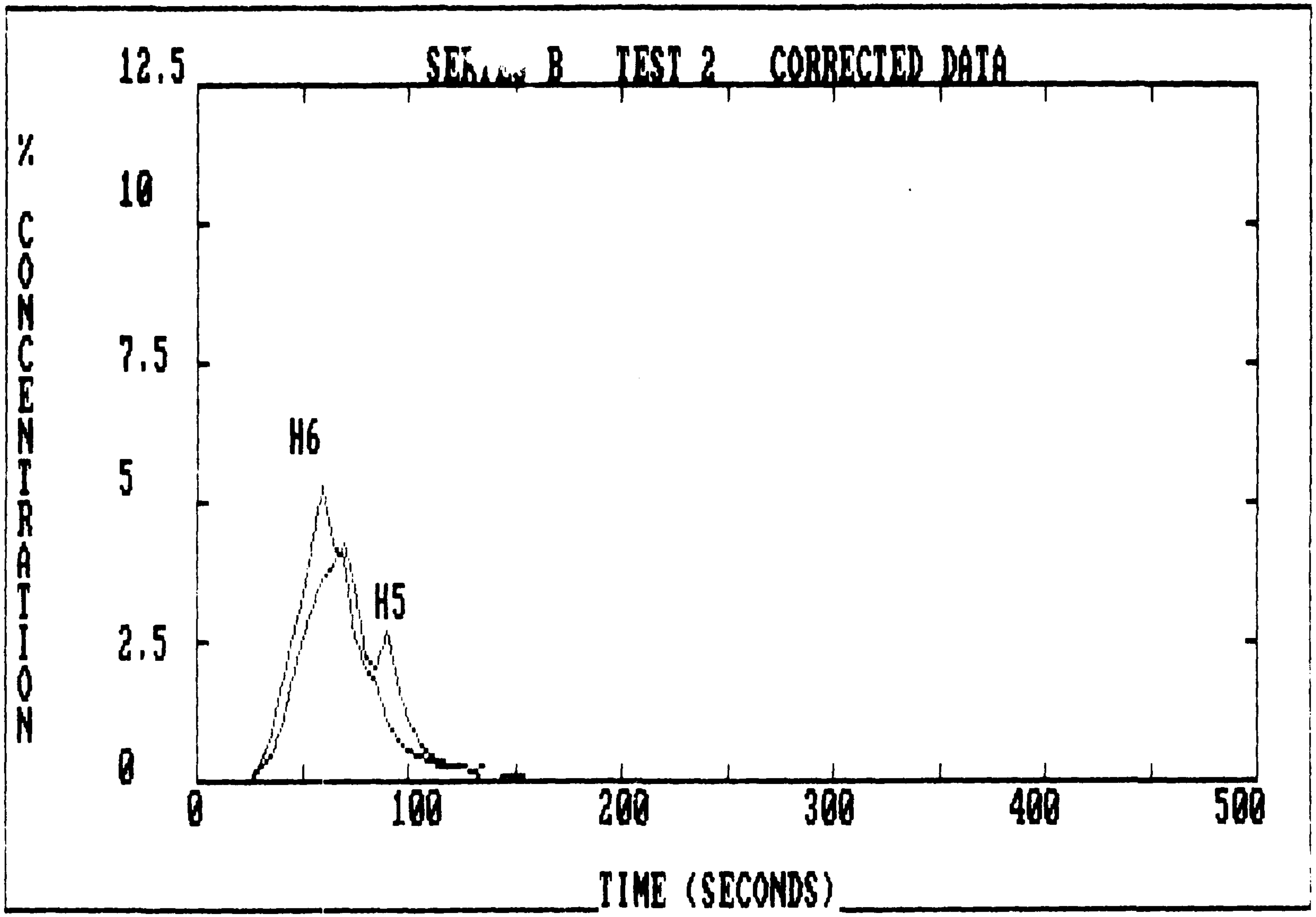



Figure C-27. Corrected Halon Concentrations for Series B, Test 2, Probes H5 and H6.

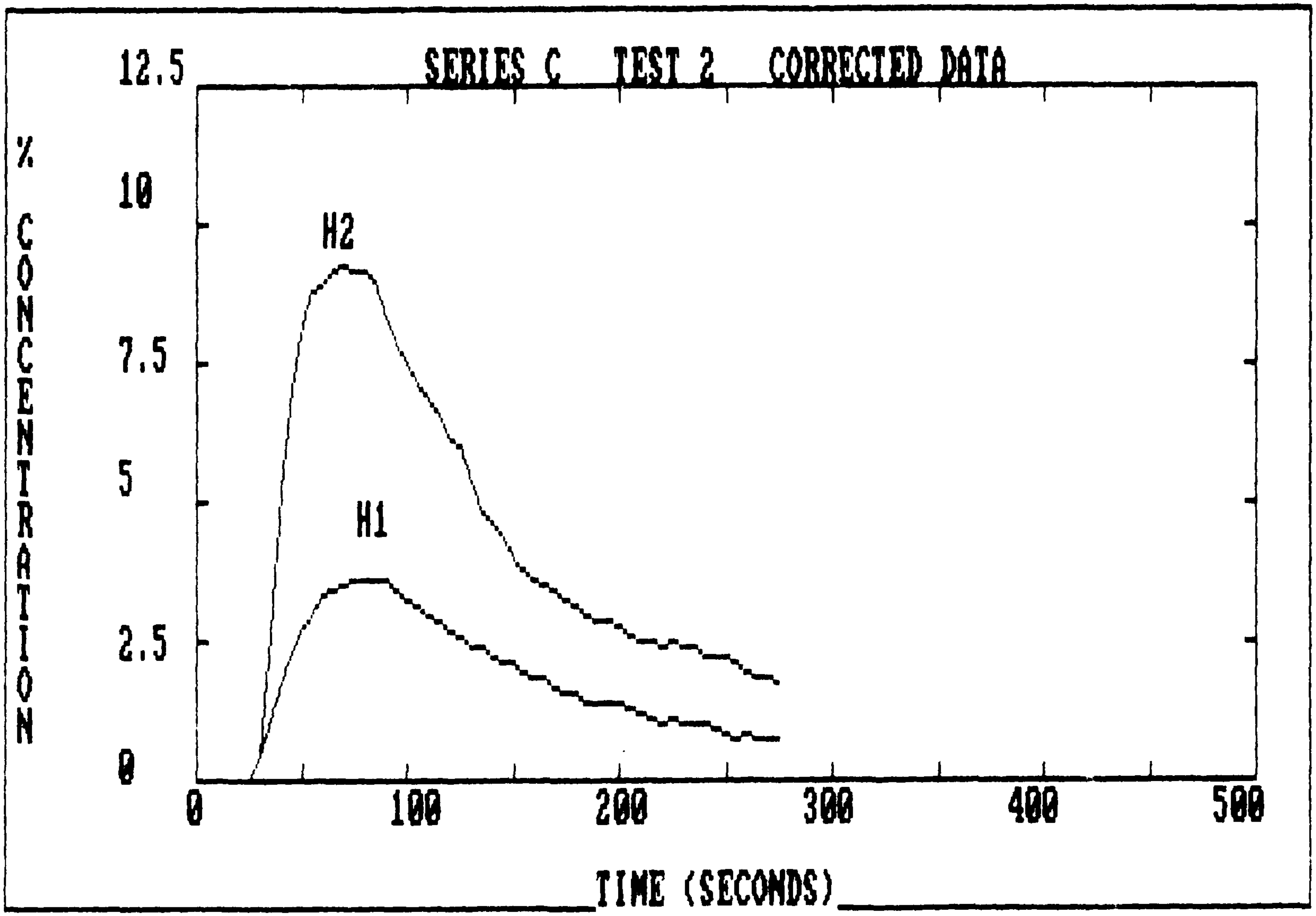



Figure C-28. Corrected Halon Concentrations for Series C, Test 2, Probes H1 and H2.

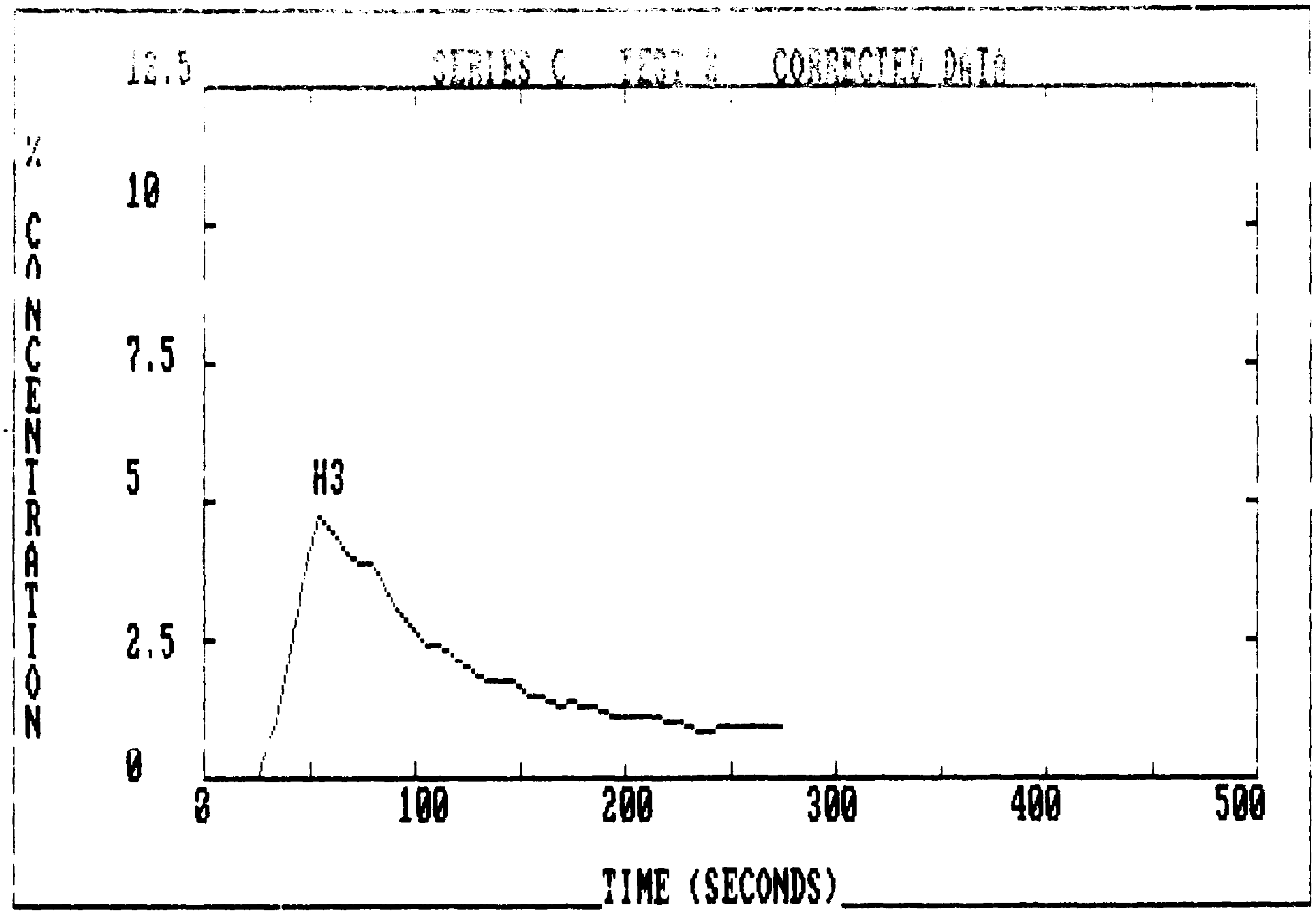



Figure C-29. Corrected Halon Concentrations for Series C, Test 2, Probe H3.

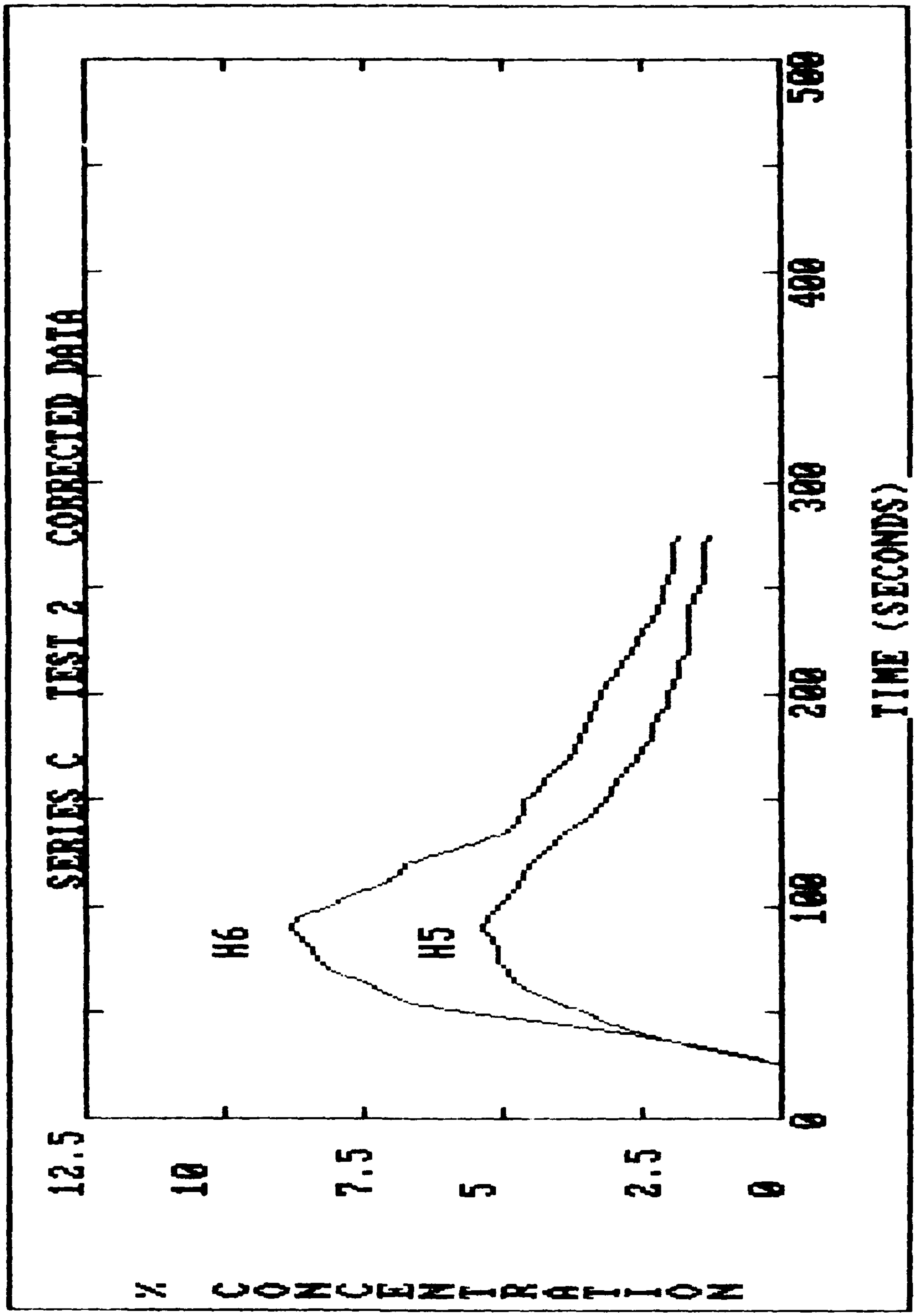



Figure C-30. Corrected Halon Concentrations for Series C, Test 2, Probes H5 and H6.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1988 — 534-090/60694



(The reverse of this page is blank.)